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VOLUME 41 FEBRUARY, 1961 No. 1

CONSUMPTIVE USE OF WATER BY FORAGE CROPS IN THE UPPER KOOTENAY RIVER VALLEY[1]

K. K. KROGMAN AND L. E. LUTWICK

Canada Department of Agriculture Research Station, Lethbridge, Alberta

[Received for publication April 28, 1960]

ABSTRACT

Consumptive use of water for alfalfa and grass was determined on Saha silt loam, a major soil of the upper Kootenay River Valley in British Columbia. Four irrigation levels, based on 0.42, 0.70, 0.83, and 1.00 times evaporation from a 4-foot buried evaporation pan, were employed. The average consumptive use of water at the highest yields obtained was 24 inches for alfalfa and 23 inches for pasture grass. Irrigation levels based on 0.83 to 1.00 times evaporation gave the highest yields.

INTRODUCTION

Many parts of the interior valleys of British Columbia are arid. Sanderson (8), using Thornthwaite's procedures, calculated water deficiencies of almost 20 inches for some of these valleys. Kirk (5) found that a water deficiency of over 10 inches prevails during the summer months in the Newgate, Cranbrook, and Wasa districts of the East Kootenay lowlands. Thus, the southern part of the Rocky Mountain Trench, as defined by Brink and Farstad (1), is an area where the future intensification of agriculture will involve irrigation.

According to Kelley and Sprout (4), there are 300,821 acres of potentially irrigable land in the upper Kootenay and Elk River Valleys, with an estimated total annual water requirement of 796,917 acre-feet. They implied that more exact estimates would require the determination of consumptive use of water by laboratory and field plot experiments. The studies reported herein were undertaken to fulfil this need.

MATERIALS AND METHODS

Irrigation plots were established on Saha silt loam about 18 miles northeast of Kimberley, British Columbia. This dark brown soil and its brown wooded counterpart, the Elko soil, comprise about one-quarter of the total irrigable acreage in the upper Kootenay and Elk River Valleys (4). The plot site was on a post-glacial flood plain with a smooth surface and an eastern slope of approximately 1 per cent. The area had not been cultivated prior to establishment of the plots. It had been used for livestock pasture and supported a thin stand of grassland vegetation, mainly spear grasses and xerophytic forbs.

A description of a Saha soil profile is given in the soil survey report (4). The soil on the plot area consisted of 8 to 10 inches of greyish brown to brown silt loam containing scattered gravel, stones, and boulders underlain by coarse sand, gravel, and stony outwash material of undetermined but considerable depth. The upper part of the substratum was slightly

[1]Contribution from the Soils Section.

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A description of a Saha soil profile is given in the soil survey report (4). The soil on the plot area consisted of 8 to 10 inches of greyish brown to brown silt loam containing scattered gravel, stones, and boulders underlain by coarse sand, gravel, and stony outwash material of undetermined but considerable depth. The upper part of the substratum was slightly

[1]Contribution from the Soils Section.

cemented, forming a caliche layer 8 to 12 inches thick. The apparent specific gravity of the soil was 1.26; the field capacity was 35 per cent; the wilting point was 8 per cent; and the infiltration rate was 1 inch per hour.

In 1956 two forage crops, 1) Ladak alfalfa, and 2) a mixture of brome grass, creeping red fescue, and orchard grass, were established on the plot area. Consumptive use of water data and yields were obtained in 1957, 1958, and 1959.

Ammonium phosphate fertilizer (11-48-0) at 100 pounds per acre was applied to all plots in the spring of each year. In addition, the grass plots were fertilized with ammonium nitrate (33.5-0-0) at 100 pounds per acre in the spring and after each harvest of hay, except the last, in each season. As severe winter-killing of the alfalfa occurred between the 1958 and 1959 seasons, this crop was replaced with Victory oats in 1959.

Increasing levels of irrigation, designated as irrigation treatments 1, 2, 3, and 4, were employed in order to determine the minimum consumptive use associated with maximum yields. A randomized block design in three replications was used.

In the spring of each year the soil moisture content of each plot, determined gravimetrically from soil samples, was used as a starting point for scheduling irrigations. A modification of the budget method as outlined by Robertson and Holmes (7) was used to schedule irrigations for the various treatments. The daily water allotment for each treatment was calculated by multiplying the evaporation from a buried 4-foot evaporation pan by 0.42, 0.70, 0.83, and 1.00 for treatments 1, 2, 3, and 4, respectively. Whenever the cumulative daily allotments reached 2.5 inches, that amount of water was applied to the respective plots. In 1958 and 1959 the plots under irrigation treatment 1 were not irrigated because of other demands on the water supply.

The water, obtained from a nearby well, was applied to the plots by sprinklers. Cans placed on the plots served as precipitation gauges for measuring the amounts of water applied. The water contained medium concentrations of salts and low concentrations of sodium as classified according to U.S.D.A. Agriculture Handbook 60 (6).

The consumptive use of water for each plot was calculated by adding together the soil moisture content in the spring and the amounts of irrigation and rainfall received during the growing season and subtracting the soil moisture content in the fall.

The alfalfa was harvested at about the 10 per cent bloom stage, the grass at early heading, and the oats at the early dough stage. The yields of all the crops are reported as total dry matter per acre. Duncan's multiple range test (3) was used to assess the significance (5 per cent level) of the differences between mean yields.

RESULTS

The yield and consumptive use of water data are shown in Table 1.

In all years yields were increased with increasing irrigation level. In 1957 and 1959 these increases were obtained up to but not beyond treatment 3 and in 1958 up to and including treatment 4.

TABLE 1. — YIELDS AND CONSUMPTIVE USE OF WATER FOR THREE FORAGE CROPS AS INFLUENCED BY IRRIGATION TREATMENT

Crop	Year		Irrigation treatment			
			1	2	3	4
Alfalfa	1957	Yield (tons/ac.)	1.50	2.26	2.99[1]	3.01
		C.U. (in.)	15.3	17.7	21.0	22.1
	1958	Yield (tons/ac.)	0.42	2.20	4.11	4.40[1]
		C.U. (in.)	7.5	16.2	24.1	26.4
Grass	1957	Yield (tons/ac.)	0.93	1.03	1.28[1]	1.37
		C.U. (in.)	15.8	18.0	20.2	22.6
	1958	Yield (tons/ac.)	0.71	1.39	1.60	1.85[1]
		C.U. (in.)	8.0	16.5	23.9	25.3
	1959	Yield (tons/ac.)	0.23	1.49	1.83[1]	1.94
		C.U. (in.)	11.9	19.5	22.3	23.4
Green oats	1959	Yield (tons/ac.)	0.84	1.41	2.05[1]	2.31
		C.U. (in.)	10.0	11.2	16.6	17.4

[1]Highest yield with a significant difference from the next lowest at the 5 per cent level

The average consumptive use of water at the highest yields obtained (those yields beyond which increasing irrigation level did not give significant yield increases) was about 24 inches for alfalfa, 23 inches for pasture grass, and 17 inches for green oats.

In 1957 and 1958 the largest yields occurred where seven and eight irrigations were applied during the growing seasons of the respective years. In 1959, when rainfall was considerably greater than in the other 2 years, the highest yield of grass was obtained where four or five irrigations were applied. The largest yield of green oats was obtained where three irrigations were applied.

Based on the results obtained, the best estimate of the rate of consumptive use of water for these crops, calculated from evaporation pan data and where soil moisture was not in limiting supply, would be from 0.83 to 1.00 times the evaporation rate.

DISCUSSION

The kind of crop grown and the length of the growing season largely determine the consumptive use of water in a given area. In this study the growing season for the perennial crops, taken as the frost-free period, was 108, 107, and 121 days in 1957, 1958, and 1959, respectively. The growing season for the oat crop, taken as the period from date of seeding to date of harvest, was 74 days. Based upon these lengths of growing season, the average daily consumptive use of water was 0.22, 0.20, and 0.22 inches for alfalfa, grass, and green oats, respectively. Therefore, the differences in the seasonal consumptive use of water by the various crops were more dependent upon the length of growing season than upon the kind of crop grown. The daily rates of consumptive use for forage crops, as determined in this study, were similar to the rate found for alfalfa in 11 western states of the United States (9). However, the total seasonal

consumptive use of water for alfalfa may vary from 18 inches in the northern mountain valleys to 54 inches in the Arizona desert, due to differences in climate and length of growing season (2).

Where no irrigation water was applied and crop growth was dependent upon rainfall alone, the yields of the forage crops were very low. At Wasa, British Columbia, located about 6 miles from the plot site and on similar topography at almost the same elevation, the average total rainfall during April to September for the years 1924 to 1954 was 6.21 inches (4). Since the present study has shown that forage crops require up to 24 inches of water, it is evident that the normal rainfall in the area is insufficient for the production of high yields of these crops.

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A STUDY OF MOISTURE STORAGE AND NITRATE ACCUMULATION IN SOIL AS RELATED TO WHEAT YIELDS ON FOUR CROPPING SEQUENCES[1]

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[Received for publication September 29, 1959]

ABSTRACT

On a clay soil at Winnipeg, Manitoba, at the University of Manitoba, four cropping sequences, namely: 1) fallow wheat; 2) fallow, wheat, wheat; 3) fallow, wheat, wheat, wheat; 4) wheat continuous have been under study since 1919. During the years 1956, 1957 and 1958 a detailed study of the relationship of wheat yields on these sequences to moisture consumption, nitrate accumulation, moisture storage and fertilizer use was undertaken. In general, yields were higher on fallowed than on non-fallowed plots. The higher yields on fallowed plots were, in part, related to nitrate accumulation during the fallow year. The yield differential between fallowed and non-fallowed plots was reduced by mineral fertilizer and manure treatments. Where no fertilizer was used the greatest wheat production in bushels per acre per year was on the fallow-wheat-wheat sequence. When fertilized or manured, the greatest production occurred on the wheat continuous plots.

Rapid accumulation of moisture took place between harvest and the following spring. As a result, during years 1956, 1957 and 1958, there was only an average of 0.7 inches more available moisture to a 4-foot depth on fallow plots at seeding time than on plots which had been cropped the previous year.

INTRODUCTION

Garland (6) reported that in 1921 about 60 per cent of the improved land in Manitoba was sown to wheat, oats, or barley and 20 per cent was fallowed. This indicates a cropping sequence of 3 years grain and 1 year of fallow. In 1956, with 50 per cent of the improved acreage devoted to cereal production and 25 per cent to fallow, the sequence would appear to be 2 years of grain followed by fallow. These data indicate the importance of the grain-fallow cropping sequence and the increasing importance of summerfallow.

Fallow acreage is probaby being increased because higher yields are normally obtained following fallow. The influence of fallow on grain yields has been explained in various ways. At Swift Current, Saskatchewan, Staple and Lehane (12, 13, 14) studied the storage of moisture during the fallow year. They concluded that, although only a small proportion of the precipitation falling in the fallow year is stored in the soil, it makes an important contribution to yield of the following crop.

Data presented by Russell (10) suggest that at Rothamsted the benefit of fallowing may be due largely to the release of nitrogen in the nitrate form. He reported that nitrogen fertilization of wheat reduced, but did not eliminate, the yield difference between fallow and non-fallow land.

In Manitoba it has been observed that grain crops grown on non-fallowed land frequently exhibit nitrogen deficiency symptoms, whereas those grown on fallowed land usually do not. Poyser *et al.* (9) reported

[1]Work supported in part by funds received from Sherritt Gordon Mines Ltd., and Harrisons and Crosfield (Canada) Ltd.

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that leguminous green manures increase the yield of wheat grown as a third crop after fallow but not when grown as a first crop after fallow. Tolton (15) found that large yield increases could frequently be obtained through nitrogen fertilization of grain grown on non-fallow land.

Hill (7) reported that in a number of cropping sequences at Lethbridge, Alberta, Indian Head, Saskatchewan, and Brandon, Manitoba, wheat yields on fallow were maintained at approximately a constant level over a 40-year period. In a 3-year fallow-wheat sequence at Indian Head yields on second-crop wheat declined gradually. He attributed this to more severe weed infestation on second-crop land and to declining soil fertility.

In an attempt to clarify the relationship of fallowing to crop yields a study was undertaken in 1956 on a number of plots which had been cropped in three fallow-wheat sequences and to wheat continuously since 1919.

MATERIALS AND METHODS

In 1956 and 1957 an experiment was performed at Winnipeg on three sequences of wheat and fallow, viz., one, two or three successive years of wheat cropping followed by fallow. A continuous succession of wheat crops was included in the study. The soil consisted of members of the Red River and Fort Garry soil associations. These are clay-textured black soils and have been described by Ehrlich *et al.* (4). This experiment was conducted on experimental land of which the crop and fertilizer history was known back to 1919 when it was first divided into experimental plots. Some of the early data from this experiment have been presented by Ellis (5).

The currently described experiment consisted of two ranges of ten plots each. From 1919 to 1931 inclusive, Range 26 received no fertilizer. However, in 1932 in this range the plots were split into two sub-plots and each north sub-plot received an application of 11-48-0 at 45 pounds per acre drilled in with the seed. In 1956 and 1957 the treatments were further modified. The fallow plots continued to receive 11-48.0 at 45 pounds per acre while the north sub-plots which had been cropped the previous year received

TABLE 1.—NITROGEN AND MOISTURE EQUIVALENT OF SAMPLES FROM SOUTH SUB-PLOTS

Plot No.	Nitrogen in per cent		Moisture equivalent in per cent			
	Surface samples		Surface		Average of five depths	
	Range 26	Range 27	Range 26	Range 27	Range 26	Range 27
1	0.195	0.222	36.1	42.1	36.6	44.6
2	0.206	0.233	36.2	41.9	37.2	43.0
3	0.293	0.339	39.8	39.0	39.0	43.0
4	0.288	0.353	39.6	40.5	41.2	41.0
5	0.296	0.345	39.4	40.2	40.3	38.1
6	0.297	0.350	39.0	41.9	41.8	41.4
7	0.280	0.312	39.4	41.4	42.6	40.7
8	0.276	0.325	40.6	40.4	42.8	42.2
9	0.334	0.386	41.1	40.2	42.1	39.7
10	0.391	0.444	38.5	39.1	40.0	38.7

27-14-0 at 160 pounds per acre drilled in with the seed. The south sub-plots remained unfertilized.

On Range 27 the plots received an application of manure at 4 tons per acre for each crop grown. The manure was applied in the fall prior to cropping, but not on plots that were to be fallowed. Here again, the plots were split in 1932 and, in addition to the manure treatments, 11-48-0 was drilled in with the seed at 45 pounds per acre on the north sub-plots. In 1956 and 1957 the north sub-plots which had been cropped the previous year received 27-14-0 at 160 pounds per acre in place of 11-48-0 at 45 pounds per acre.

The arrangement of crops for 1956 on Ranges 26 and 27, together with the sequence represented, was as follows:

Plot No.	*Crop in 1956*	*Cropping Sequence*
1	1st year wheat	Fallow-wheat
2	Fallow	
3	1st year wheat	
4	2nd year wheat	Fallow-wheat-wheat
5	Fallow	
6	1st year wheat	
7	2nd year wheat	Fallow-wheat-wheat-wheat
8	3rd year wheat	
9	Fallow	
10	Wheat	Wheat continuous

In this experiment there is no true replication and, therefore, no statistical basis for estimating real differences in yield between cropping sequences and between manure and fertilizer treatments. The consistent increases in yield obtained from manure and fertilizer treatments indicate that the differences are real.

In 1956 and 1957, all of the 40 plots were sampled to determine the moisture content in the spring just before seeding and fertilizing (about May 1), at harvest (about August 15), and shortly before freeze-up (about October 15). Sampling was incomplete in October, 1956, due to wet weather just before freeze-up. In 1957, nitrate nitrogen was determined on all samples collected. Plots were also sampled for moisture and nitrate determinations in May, 1958.

Samples were taken at depths of 0 to 6 inches, 6 to 12 inches, 12 to 24 inches, 24 to 36 inches, and 36 to 48 inches on all plots. In 1957 and 1958 samples were taken at depths of 48 to 60 inches and 60 to 72 inches on 20 plots, namely, the north and south halves of plots 3, 4, 5, 9, and 10 on Ranges 26 and 27.

The moisture content was determined by drying the samples at 110°C. immediately after sampling. Nitrate was determined colorimetrically by the phenoldisulphonic acid method.

The moisture equivalent was determined by the method of Briggs and McLane (2). The wilting coefficient was calculated by multiplying the moisture equivalent by 0.54 (dividing by 1.85). Other workers (11, 16, 17) have shown that the moisture equivalent of heavy-textured soils ranges from

1.80 to 1.99 times the wilting coefficient. Consumptive use of moisture was calculated by adding the precipitation between the May and August samplings to the decrease in available moisture between these two dates.

Data for the nitrogen content of surface samples and the moisture equivalent data for surface samples and for the average of the five depths are presented for the south sub-plots in Table 1. The nitrogen was determined by the Kjeldahl-Gunning-Arnold method (1). Nitrogen values show a general increase from the lower to the higher numbered plots. The lower nitrogen content of the lower numbered plots could be due to difference in initial nitrogen content. However, as analyses are not available for the earlier years of the experiment this may not necessarily be the case. It is possible that the more frequent fallowing of the low numbered plots has resulted in a decline in nitrogen content.

Moisture equivalent values are the lowest for the plots 1 and 2 of Range 26. In most instances the variations between plots and between surface samples and the average of the five depths were within 2 or 3 per cent.

RESULTS

Yield

The yield data for 1956 and 1957 are presented in Table 2. As was to be expected, the mean yield of the check plots was lowest on the third crop wheat and on wheat continuous and the yields were successively higher the more closely they succeeded fallow. In all sequences, the first crop following fallow gave the highest yield.

Fertilizer and manure treatments resulted in consistent increases in yield. Yield increases from manure application were greater on stubble than on fallow plots. This is in keeping with results reported by Russell (10) and indicates that part of the benefit of fallowing is its effect on the supply of available nutrients.

TABLE 2.—YIELD OF WHEAT (2-YEAR MEAN) AS INFLUENCED BY FERTILIZER AND MANURE TREATMENTS WHEN WHEAT IS GROWN CONTINUOUSLY AND AS FIRST, SECOND AND THIRD CROP AFTER FALLOW
(bushels per acre)

Rotation	Treatment					
	Crop year	Check	Mineral fertilizer[1]	Manure 4 tons/crop	Manure and fertilizer	Mean
Continuous		21.6	38.0	39.3	40.0	34.7
F-W-W-W	3rd	19.6	34.6	34.6	38.9	31.9
F-W-W-W	2nd	26.6	38.0[2]	36.9	42.6[2]	36.0
F-W-W-W	1st	40.9	42.9	51.4	51.8	46.7
F-W-W	2nd	35.3	40.6	40.9	45.3	40.5
F-W-W	1st	41.3	44.3	45.6	50.9	45.5
F-W	1st	41.6	46.9	41.6	48.0	44.5
Mean		32.4	40.7	41.4	45.3	

[1] 11-48-0 @ 45 pounds per acre for first crop after fallow; otherwise 27-14-0 @ 160 pounds
[2] 1957 data only

TABLE 3.—ANNUAL WHEAT PRODUCTION PER UNIT AREA OF LAND AS INFLUENCED BY CROPPING SEQUENCE AND FERTILITY TREATMENTS
(bushels per acre)

Rotation	Treatment			
	Check	Mineral fertilizer[1]	Manure 4 tons/crop	Manure and fertilizer
Continuous	21.6	38.0	39.3	40.0
F-W-W-W	21.7	28.9	30.7	33.3
F-W-W	25.5	28.0	28.8	32.0
F-W	20.8	23.4	20.8	24.0

[1] 11-48-0 @ 45 pounds per acre for first crop after fallow; otherwise 27-14-0 @ 160 pounds

Due to the difference in the mineral fertilizer treatments on fallow and stubble plots it is not possible to make comparisons between stubble and fallow where mineral fertilizers were applied. In spite of the difficulty in making comparisons it should be observed that mineral fertilizer treatments gave yield increases on both fallow and stubble plots which compare closely with those obtained from the manure treatments. The manure and mineral fertilizer treatment combined gave somewhat larger yield increases on both fallow and stubble than did manure and mineral fertilizer treatments applied individually.

Wheat production in bushels per acre per year for the different cropping sequences is presented in Table 3. These data indicate that where fertilizer and manure are not applied the greatest wheat production is obtained on the 3-year fallow-wheat sequence. These results suggest that, since it is usually less costly to summerfallow than to grow a crop, the common practice in Manitoba of summerfallowing every third year is the most profitable sequence when little or no fertilizer or manure is used. It is noteworthy that the data of this experiment furnish evidence that much higher production can be obtained if the fallow is omitted and fertilizer or manure is used. As weed control is less difficult on small plots than on farm fields, this might not hold under farm conditions, although the authors are aware of one instance where a farm operator has substituted use of mineral fertilizer for periodic fallowing and has now grown grain on the same land for seven consecutive years, obtaining above average yields each year.

Moisture Relations

Consumptive use of water (evapo-transpiration) by the wheat crop varied considerably on individual plots, although in the majority of cases the values fell between 12 and 15 inches (Table 4). Consumptive use was slightly lower on the check plots in both years, particularly in 1957. Average consumptive use for all sequences and all fertilizer treatments was the same for the two seasons. In 1956, when the soil was very dry at harvest, there was a significant correlation (+0.54**) between yield and consumptive use of water. This suggests that moisture deficit may have limited wheat yields. In 1957 the correlation (+0.23) between yield and consumptive use was not significant. In both years higher yields were associated with increased

TABLE 4.—CONSUMPTIVE USE OF WATER AS AFFECTED BY MANURE AND FERTILIZER TREATMENT
(inches)

Rotation	Crop year	Treatments			
		Check	Fertilizer	Manure	Manure and fertilizer
			— 1956 —		
Continuous		12.9	12.9	13.9	14.4
F-W-W-W	3rd	9.5	12.5	13.0	13.4
F-W-W-W	2nd	11.2	11.1	14.8	12.2
F-W-W-W	1st	11.5	12.8	14.0	15.2
F-W-W	2nd	14.6	12.5	15.9	12.8
F-W-W	1st	15.1	13.2	13.1	12.3
F-W	1st	16.0	17.8	13.2	12.2
	Means	13.0	13.3	14.0	13.2
			— 1957 —		
Continuous		12.4	14.5	13.3	13.8
F-W-W-W	3rd	12.9	13.2	14.3	14.1
F-W-W-W	2nd	12.5	14.3	11.2	14.0
F-W-W-W	1st	11.0	13.1	14.1	12.0
F-W-W	2nd	12.3	11.1	14.3	16.0
F-W-W	1st	12.0	12.6	15.6	16.2
F-W	1st	12.0	13.8	15.8	12.3
	Means	12.2	13.2	14.1	14.1

efficiency in water use. This is indicated by the relationship between yield of wheat and bushels of wheat produced per inch of water used. Correlations were +0.83** and +0.85** for 1956 and 1957, respectively.

The results in Table 5 indicate that, under the conditions of this experiment, a smaller percentage of the moisture which fell during the fallow period was stored in the soil at seeding time than was reported by Staple and Lehane (10). In the winter of 1955-56, snowfall was very heavy. In the spring of 1956, plots fallowed in 1955 and cropped in 1955 contained an average of 7.6 and 5.8 inches of available moisture, respectively. Plots fallowed in 1956 actually lost moisture between the May and August sampling dates, although 8.9 inches of precipitation fell during this period. Weed growth was not permitted to take place, so loss of moisture must have been due to evaporation or percolation. Available moisture in plots fallowed in 1956 increased from 4.5 inches in August to 7.7 inches by the following spring. Final storage of moisture was 7.0 per cent of the moisture which fell during the year.

Similar results were obtained on plots in fallow during the period August 1956 to May 1958. These plots showed a rapid increase in moisture content from August 1956 to May 1957. Once again, a loss of moisture occurred during the summer months, despite precipitation of 10.2 inches. Moisture content of the soil increased between August and October, but a loss occurred between October and May. The loss of moisture during the winter months of 1957-58 was due to a very low precipitation from October to May and also because seeding was delayed during the spring of 1958 until the latter part of May and sampling of the soil was similarly postponed.

TABLE 5.—RAINFALL IN 1956, 1957 AND 1958 AND MOISTURE ACCUMULATION TO A 4-FOOT DEPTH ON FALLOW AND CROPPED PLOTS

	May 1956 to May 1957				August 1956 to May 1958					
	May to August	August to October	October to May	May 1956 to May 1957	August to October	October to May	May to August	August to October	October to May	Aug. 1956 to May 1958
Rainfall — inches	8.9	6.2	9.9	25.0	6.2	9.9	10.2	4.2	3.6	34.1
	Fallow in 1956				Fallow in 1957					
Moisture accumulated on fallow — inches	−1.3	1.9	1.3	1.9	3.5	3.3	−1.1	0.8	−2.1	4.4
Moisture accumulated on fallow — per cent		31.0	12.6	7.0	56.2	33.1		19.3		12.9
Available moisture to 4 feet — inches	5.8-4.5	4.5-6.4	6.4-7.7	5.8-7.7	1.8-5.3	5.3-8.6	8.6-7.5	7.5-8.3	8.3-6.2	1.8-6.2
	Stubble-cropped in 1955 and 1956				Stubble-cropped in 1956 and 1957					
Moisture accumulated on stubble — inches	−4.1	3.1	3.4		3.1	3.4	−3.8	0.9	−0.2	
Moisture accumulated on stubble — per cent		50.0	34.3		50.0	34.3		21.4		
Available moisture to 4 feet — inches	5.8-1.7	1.7-4.8	4.8-8.2		1.7-4.8	4.8-8.2	8.2-4.7	4.7-5.6	5.6-5.4	

Note: Plots fallowed in 1955 had an average of 7.6 inches stored moisture in May 1956

On plots which were cropped in 1955 and again in 1956, the level of available moisture was reduced to 1.7 inches by harvest in 1956. During the fall and winter months precipitation was above normal and a rapid accumulation of moisure took place. Thus, by May 1957, there was actually slightly more stored moisture in these plots than on those fallowed in 1957. During the summer of 1957 there was a reduction in the amount of available moisture on cropped plots but the moisture content at harvest was considerably higher than at harvest in 1956. This was no doubt due to the relatively high precipitation in the summer of 1957 and particularly to the fact that 1.9 inches of rain fell during the first 2 weeks of August. There was an increase in stored moisture between August and October of 1957. During the winter of 1957-58 the moisture content of stubble plots remained approximately unchanged, whereas on fallow plots there was a sharp decline in moisture. As a result, in the spring of 1958, as in the spring of 1957, there was approximately the same amount of stored moisture in stubble as in fallow plots at seeding time.

The results indicate that when soils are dry a large percentage of the precipitation remains in the soil as available stored moisture. Once the moisture content of the soil has reached a certain level further accumulation of moisture does not take place. As indicated by Lehane and Staple (8), the maximum storage level is appreciably below the theoretical maximum as calculated from field capacity and wilting coefficient data.

Under conditions of relatively high rainfall, which occurred during the period under study, the fallow plots became saturated and ceased storing moisture with the result that in the spring of the year there was nearly as much stored moisture in cropped as in fallowed plots.

In May of 1956, 1957 and 1958 fallowed plots had 7.6, 7.7 and 6.2 inches of available moisture to a 4-foot depth, respectively. Comparable figures for stubble plots were 5.8, 8.2 and 5.4 inches, respectively. Thus, during the period under study, fallowing increased average moisture storage by 0.7 inches at seeding time as compared to plots which had not been fallowed.

TABLE 6.—INCREASE IN NITRATE NITROGEN ON FALLOW PLOTS TO A DEPTH OF 3 FEET MAY TO OCTOBER 1957 AND NITRATE CONTENT IN MAY OF 1957 FOR THREE CROPPING SEQUENCES (pounds per acre)

Treatment	Cropping sequence			Average
	F-W	F-W-W	F-W-W-W	
Check	30.9	—3.9	49.5	25.5
Fertilizer	22.6	30.4	40.1	31.0
Manure	39.3	57.1	76.7	57.7
Manure and fertilizer	39.7	48.9	51.1	46.6
Average increase	33.1	33.1	53.5	
Average in May 1957	5.9	14.2	6.5	

Nitrate Accumulation in Fallow Year

Plots fallowed in 1957 had an average of 8.8 pounds of nitrogen in the nitrate form in May of that year. The nitrate content increased rapidly (Table 6). The application of manure increased accumulation of nitrate. The frequency of fallowing also appears to have influenced nitrate accumulation with those sequences having the largest proportion of fallow giving the lowest accumulation. Total soil nitrogen is lowest in these instances and this may affect nitrate accumulation. The lower nitrogen content of the more frequently fallowed plots could have been, in part at least, a result of more frequent fallowing. However, since analyses of the plots for total nitrogen are not available for more than one date, it is not possible to draw any conclusions in this regard.

Nitrate Nitrogen at Seeding Time

Data are presented in Table 7 giving the nitrate nitrogen to the 3-foot and 2-foot depths at seeding time together with yield data. The 3-foot depth was selected because on these clay soils wheat usually removes all the nitrate nitrogen to this depth by harvest time. In some plots the nitrate content remained quite high in the third foot throughout the year and, therefore, data for the first 2 feet are also presented. Below 3 feet there was usually a fairly high nitrate content throughout the year. A few plots were sampled to a depth of 6 feet and found to contain up to 44 p.p.m. nitrate nitrogen at this depth. This is consistent with results reported by Doughty *et al.* (3) and is probably due to leaching during the fallow year.

TABLE 7.—NITRATE-NITROGEN IN SOIL IN MAY OF 1957 AND YIELD OF WHEAT AS RELATED TO FERTILIZER TREATMENT

Fertility treatment	Nitrate-nitrogen — lb./acre		Yield bu/.ac.	Increase due to manure and/or fertilizer bu./ac.
	to 3-foot depth	to 2-foot depth		
	1st crop F-W-W			
Check	31.2	24.5	40.0	
Fertilized 11-48-0 @ 45 lb.	24.2	19.9	41.3	1.3
Manure — 4 tons	32.5	20.5	45.3	5.3
Manure and fertilizer	55.0	33.3	47.3	7.3
	1st crop F-W-W-W			
Check	25.4	16.3	44.6	
Fertilized 11-48-0 @ 45 lb.	26.0	19.4	44.6	0.0
Manure — 4 tons	41.6	27.2	49.6	5.0
Manure and fertilizer	42.3	32.3	49.6	5.0
	2nd crop F-W-W			
Check	25.7	12.6	29.3	
Fertilized 27-14-0 @ 160 lb.	42.5	13.9	40.0	10.7
Manure — 4 tons	43.1	19.7	32.6	3.3[1]
Manure and fertilizer	17.3	14.0	42.6	13.3
	Av. 2nd and 3rd crop of F-W-W-W			
Check	9.8	9.3	20.7	
Fertilized 27-14-0 @ 160 lb.	7.5	7.5	35.7	15.0
Manure — 4 tons	19.5	12.1	34.6	13.9
Manure and fertilizer	9.8	8.6	39.6	18.9

[1] Yield increase from this treatment in 1956 was 8.0 bushels per acre

In the spring of 1957 the plots which had been fallowed the previous year contained approximately 35 pounds per acre of nitrate nitrogen to a 3-foot depth and 25 pounds per acre of nitrate nitrogen to a 2-foot depth. Since there was considerable utilization of this accumulated nitrate, wheat on fallow obtained nitrate from the reserves in the soil in addition to that produced by micro-organisms during the growing season. The nitrogen so obtained appears to have been nearly adequate for the crop. High yields were obtained without fertilizer and neither the manure nor the mineral fertilizer resulted in nearly as large yield increases as were obtained on stubble plots.

Direct comparison of yield can be made between fallow and stubble plots on the manure only fertility treatment. The use of 27-14-0 at 160 pounds per acre on wheat after stubble and 11-48-0 at 45 pounds per acre on wheat after fallow means that nitrogen rate is confounded with crop sequence. Therefore, comparisons of the effects of stubble and fallow with mineral fertilizer require qualification to this extent.

On the stubble plots of the 4-year fallow-wheat sequence the nitrate content of the soil to 2-foot and 3-foot depths in the spring was less than 10 pounds per acre on all except the manure only plots. Thus, the nitrogen made available during the growing season was virtually all that the crop obtained. On these plots check yields were low and large yield increases were obtained from the manure and mineral fertilizer treatments.

The stubble plots of the 3-year fallow-wheat sequence had a nitrate content in the upper 3 feet nearly the same as that in the upper 3 feet of the fallow plots. However, there was generally less nitrate in the upper 2 feet in these plots than in the fallow plots. In this cropping sequence the check yield was higher than the check yield on the 4-year fallow-wheat sequence. Here the response to the manure treatment was quite low. The response to the application of 27-14-0 and manure plus 27-14-0 was quite high.

GENERAL DISCUSSION

The summerfallow acreage has increased in Manitoba in recent years despite above normal precipitation and the advent of chemical weed control. The data presented suggest that in the Red River Valley area of Manitoba fallowing may contribute little or nothing to moisture reserves at seeding time. However, fallowing may result in good crops of wheat where fertilizer or manure is not used. With weeds under control an even higher average production should be possible by continuous cropping coupled with the use of nitrogen-phosphorus fertilizer or manure. The reduction of fallowing can also be expected to reduce wind and water erosion.

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EFFECTS OF DIFFERENT SOIL MOISTURE TENSIONS ON GRASS AND LEGUME SPECIES[1]

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ABSTRACT

Established stands of three grasses and legumes, grown in a greenhouse, were subjected to flooding treatments consisting of soil moisture tensions of approximately 0, 25 and 40 centimetres of water which were equivalent to field conditions where the water table is at the soil surface, 25 and 40 centimetres below the soil surface, respectively. Herbage and root yields were measured.

Grasses were more tolerant to flooding than were the legumes. The order of decreasing tolerance to flooding was: reed canary grass, timothy, brome grass, birdsfoot trefoil, Ladino clover and alfalfa. The yields of grasses tended to increase with increasing moisture levels and with durations of flooding, whereas the yields of legumes tended to decrease with increasing moisture levels and with the duration of flooding.

The effect of flooding on yields was more pronounced on the first than on the second harvest. Highly significant positive correlation coefficients were obtained between total top and root weights of reed canary grass, birdsfoot trefoil, Ladino clover and alfalfa. Corresponding correlation coefficients for timothy and brome grass were negative and highly significant.

Oxygen diffusion measurements indicated that, in general, the yields of legumes increased with increasing availability of oxygen whereas the yields of grasses showed a tendency to decrease. As the soil temperature under flooding conditions increased from 41° to 80°F. the forage yields usually decreased.

INTRODUCTION

Little information is available on the established stands of different species though some attention has been devoted to the effect of flooding conditions on the emergence of forage species. Bolton and McKenzie (1) investigated the tolerance of different crops to spring flooding conditions and found that, of the species studied, timothy and reed canary grass were the most tolerant. Brome grass, slender wheat grass and meadow fescue withstood fairly long periods of flooding whereas sweet clover, alfalfa and crested wheatgrass endured only short periods of flooding. Finn[3] tested four legume and four grass species under complete flooding for a 1-week period. He found the grasses more tolerant to flooding than the legumes; reed canary grass withstood flooding better than Chewing's fescue; and timothy and brome grass were the least tolerant of the grasses. The order of increasing tolerance of the legumes was: alfalfa, sweet clover, alsike clover, and Ladino clover. McKenzie (6) studied the ability of forage plants, at three stages of growth, to survive early spring flooding. He found that grasses were more tolerant than legumes to flooding at all stages of growth; that the more tolerant grasses were reed canary grass, timothy, western wheatgrass, meadow fescue, Virginia wild rye, and common brome grass; and that creeping red fescue and orchard grass exhibited less tolerance to flooding.

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The study reported here was initiated to evaluate the effects of different degrees of flooding, for three periods of different length, on three grass species and three legume species.

MATERIALS AND METHODS

The study was conducted in a greenhouse, during the winter season of 1957-58, using glazed gallon pots filled with 10 pounds of Castor silt loam. The texture of the soil was 30 per cent sand, 55 per cent silt, and 15 per cent clay. The total porosity of the soil in the pots was 54 per cent. The percentages of air space in the soil at 0-, 25- and 40-centimetre tensions were 0, 14 and 20, respectively. The following species were planted:

Timothy	8 per pot
Brome grass	6 per pot
Reed canary grass	6 per pot
Alfalfa	5 per pot
Birdsfoot trefoil	6 per pot
Ladino clover	2 per pot

Where grasses were grown the soil was fertilized at the rate of 20, 60, 50 pounds of N, P_2O_5 and K_2O respectively per acre, using the soil weight as a basis. Where legumes were grown the N application was lowered to 10 pounds but the other two nutrients remained the same.

Supplemental incandescent light was used when needed during the experiment to maintain a 16-hour day.

Ninety days after emergence, and prior to heading, the grasses and legumes were cut back to 5- and 4-inch heights respectively.

The grass and legume species were then subjected to flooding treatments, consisting of moisture tensions of approximately 0, 25 and 40 centimetres of water at the soil surface which were equivalent to field conditions with the water table at the soil surface, at 25 and at 40 centimetres below the soil surface respectively. In addition, a treatment was set up where soil moisture was maintained at approximately field capacity by regular weighings throughout the experiment. The 0-centimetre treatment was established by placing gallon pots in a large water bath. The level of water in the bath was maintained 1 centimetre above the surface of the soil in the pots. The technique developed by Bourget *et al.* (2) was used for the 25- and 40-centimetre treatments. The soil was saturated, the filter cups were connected to a vacuum line and evacuation was maintained until there were no air bubbles in the line. The hydraulic conductivity of the porous ceramic material of the filter cups was 75,000 cm./hr./in. of thickness and that of the soil in the pots was found to be 20 cm./hr. Tensiometers were inserted at random to check the soil moisture tensions. The latter were found to be maintained at approximately 0, 25 and 40 centimetres of water at the soil surface throughout the experiment. The flooding treatments were maintained for periods of 10, 20 and 30 days. The treatments were duplicated and the pots randomized within each replicate. Soil moisture was maintained near field capacity before and after the flooding periods. Oxygen diffusion measurements (5) were made while the flooding treatments were in progress.

TABLE 1.—YIELDS OF GRASSES AS AFFECTED BY DIFFERENT SOIL MOISTURE LEVELS FOR PERIODS OF 10, 20 AND 30 DAYS
(Yields of dry matter — grams per pot)

Crop	Duration of flooding at different tensions									Standard error	D.F.	Yield at field capacity
	10 days			20 days			30 days					
	0 cm.	25 cm.	40 cm.	0 cm.	25 cm.	40 cm.	0 cm.	25 cm.	40 cm.			
Brome grass												
Cut 1	3.98	3.00	2.58	3.43	3.68	2.55	4.65	3.60	3.00	0.26	8	2.30
Cut 2	0.88	1.45	0.83	1.03	0.98	0.73	1.25	1.30	0.98	0.13	8	0.88
Roots	10.03	11.20	11.70	8.98	9.60	12.15	10.65	11.80	9.65	0.75	8	10.16
Reed canary grass												
Cut 1	4.58	5.15	3.90	4.78	4.25	3.78	5.08	4.40	4.55	0.21	8	3.74
Cut 2	2.60	2.13	2.43	2.90	2.33	2.43	3.13	2.65	2.85	0.08	8	2.75
Roots	9.98	7.50	10.33	10.33	9.98	8.68	9.75	10.13	9.18	0.31	8	9.73
Timothy												
Cut 1	5.55	5.10	5.03	5.90	4.45	4.48	5.33	4.53	4.38	0.35	8	5.78
Cut 2	2.63	2.13	3.30	2.90	2.35	3.30	3.55	2.85	2.65	0.09	8	2.75
Roots	8.15	5.70	7.55	9.33	5.80	6.65	7.55	7.85	6.63	0.69	8	8.98

The first and second cuts of herbage were made 30 and 60 days respectively after the last (30-day) flooding period. After the second cutting the roots were removed from the soil and washed in a wet sieving apparatus (3). All the tissue was oven dried and the dry matter determined.

Since it was observed that the temperature of the water in the water bath where the zero tension was applied varied from 67°F. to 80°F., it was decided to conduct a further investigation on the effect of soil temperature and periods of flooding on the herbage yields of plants. This experiment was conducted in duplicate using brome grass, birdsfoot trefoil, alfalfa and Ladino clover at zero tension for periods of 1, 2 and 3 weeks. The pots were flooded in constant temperature tanks (4) at temperatures of 41°, 54°, 67° and 80°F. Following the 3-week flooding period the plants were grown for 30 days and harvested.

RESULTS AND DISCUSSION

Yields of Grasses

Dry matter yields for grasses are recorded in Table 1. The first-cut yields of all three grasses usually increased with increasing soil moisture levels (decreasing tensions). The trend was similar for the yields of brome grass and reed canary grass in the second cut. Yields of timothy did not show any consistent trend. Yields of the three grasses, for both harvests, increased with lengthened periods of flooding in the majority of cases. The most consistent exception to this was with the first-cut yields of timothy where flooding adversely affected the yields, causing a decrease. The highest herbage yields of reed canary grass in the second harvest were produced consistently at the highest soil moisture level (0-centimetre tension).

The root weights of the three grasses tended to decrease with increasing tensions with the exceptions of brome grass for the 10- and 20-day periods and of reed canary grass for the 10-day period.

Statistical analyses showed some significant differences in herbage and root yields of reed canary grass and in the herbage yields of brome grass for the first harvest and of timothy for the second harvest.

Highly significant negative correlation coefficients were obtained between the total yields (cut 1 plus cut 2, including data for the three periods) of forage and of roots, namely, for brome grass ($r - 0.663$) and timothy ($r - 0.879$). In the case of reed canary grass there was a highly significant positive correlation ($r + 0.924$).

The yields of grasses for the field capacity treatment were frequently lower than those for other treatments.

Yields of Legumes

Dry matter yields for legumes are given in Table 2. Alfalfa was the least tolerant to flooding. Yields decreased consistently with decreasing tensions and at zero tension, yields were very small. As the period of flooding increased, yields of alfalfa tops usually decreased. By the time of the second cutting, the alfalfa plants which had grown at 25- and 40-

TABLE 2.—YIELDS OF LEGUMES AS AFFECTED BY DIFFERENT SOIL MOISTURE LEVELS FOR PERIODS OF 10, 20 AND 30 DAYS
(Yields of dry matter — grams per pot)

Crop	Duration of flooding at different tensions									Standard error	D.F.	Yield at field capacity
	10 days			20 days			30 days					
	0 cm.	25 cm.	40 cm.	0 cm.	25 cm.	40 cm.	0 cm.	25 cm.	40 cm.			
Alfalfa												
Cut 1	1.40	3.28	5.30	0.83	1.05	3.15	0.70	1.28	2.30	0.26	8	8.75
Cut 2	1.25	4.58	4.63	0.25	3.53	3.80	0.73	3.08	3.73	0.50	8	5.52
Roots	1.33	8.03	9.73	0.98	4.33	7.88	1.73	2.88	6.33	0.45	8	13.76
Ladino clover												
Cut 1	7.10	5.70	7.38	6.45	6.08	6.53	4.93	7.45	9.83	0.99	8	8.21
Cut 2	5.75	6.05	6.65	5.33	5.38	7.93	5.75	4.45	8.80	0.52	8	8.58
Roots	4.35	4.08	3.65	3.38	3.68	3.85	3.28	3.40	4.43	0.34	8	4.89
Birdsfoot trefoil												
Cut 1	6.38	5.35	6.68	2.40	5.40	5.10	2.40	4.73	6.25	0.72	8	6.24
Cut 2	5.40	4.68	5.18	5.48	4.55	4.28	5.70	4.23	3.25	0.20	8	4.40
Roots	5.60	6.85	5.65	5.63	6.10	7.73	5.03	5.40	7.43	0.35	8	7.62

centimetre tensions for the different lengths of time had recovered quite well. Those at zero tension, even for 10 days, never recovered. The pattern of sensitivity of roots to flooding was similar to that of the tops.

Ladino clover showed tolerance to flooding up to the 20-day period. With the 30-day treatment, first-cut yields at zero tension were only about half of those obtained at 40-centimetre tension. This effect of flooding was still apparent at the time of the second cutting but to a lesser degree. Root yields of Ladino clover reflected the tension treatments for the 20- and 30-day periods in that there were less roots with lowering soil moisture tension.

Birdsfoot trefoil showed good tolerance to complete flooding for 10 days as shown by first-cut yields. After 20 and 30 days of flooding, however, the yields were smaller at zero than at the higher tension. By the time of second cutting the birdsfoot trefoil had completely recovered from the adverse effects of flooding, and indeed, where the 0-centimetre flooding had taken place for 30 days, the second-cut yield was better than the yields from any of the other treatments. Root yields of birdsfoot trefoil showed some sensitivity to increasing soil moisture and yields of roots were less for the complete flooding treatment than for the others. Root yields tended to be less with increasing periods of flooding for the zero and 25-centimetre tensions.

Some significant differences were obtained in both herbage and root yields of alfalfa and birdsfoot trefoil and in the herbage yields of Ladino clover for the second harvest.

The correlation coefficients between total foliage yields (cut 1 plus cut 2, including data for the three periods) and root yields were positive and significant, namely, for alfalfa ($r + 0.977$), for Ladino clover ($r + 0.888$) and birdsfoot trefoil ($r + 0.805$).

With the exception of birdsfoot trefoil the yields of legumes for the field capacity treatment were usually higher than those for other treatments.

Oxygen Diffusion Measurements

Table 3 shows the relationship between the soil moisture levels and the availability of oxygen in the soil. In all cases the availability of oxygen increased as the amount of water in the soil decreased. The variation in

TABLE 3.—THE EFFECT OF DIFFERENT LEVELS OF SOIL MOISTURE ON AVAILABILITY OF OXYGEN IN THE SOIL
(Diffusion of oxygen — gm. $X10^{-8}/cm.^2/min.$)

Crop	0-cm. tension	25-cm. tension	40-cm. tension	Field capacity
Reed canary	4.4	9.1	10.1	24.2
Timothy	4.6	7.6	17.1	22.5
Brome grass	5.2	6.7	18.4	24.1
Birdsfoot trefoil	4.1	8.0	10.3	37.2
Ladino clover	4.4	5.2	7.8	27.9
Alfalfa	4.2	8.0	11.0	27.8

oxygen availability for the different species was small at high moisture levels and it tended to increase with decreasing moisture. The significance of this interaction is uncertain because the limits of accuracy of the oxygen diffusion technique were not determined and because the diffusion measurements were confounded by root respiration which may have varied among species and treatments.

Comparisons of the yield data in Tables 1 and 2 with the oxygen diffusion measurements show that the legumes gave a positive response to an increase in oxygen availability whereas the grasses tended to respond negatively.

Soil Temperature

The effect of soil temperature on tolerance of four forage species to complete flooding for three different periods of time is shown in Table 4.

Yields of alfalfa, under flooding conditions, usually decreased with increasing temperature. The degree of tolerance to flooding decreased with increased periods for all soil temperatures. The differences between yields at 54°F. and 67°F. suggest this was a critical range for alfalfa with much poorer tolerance at the higher end of the range.

Ladino clover was less sensitive than alfalfa to changes in soil temperature under flooding conditions except at 80°F. for the 7-day period. Resistance against adverse effects of flooding increased progressively with the increase in periods at the 80° temperature indicating some adaptation of Ladino clover to this condition. There was also a tendency for more resistance against adverse effects of flooding at the two lower temperatures where flooding occurred longer than 7 days.

TABLE 4.—RELATIONSHIP OF SOIL TEMPERATURE AND PERIODS OF COMPLETE FLOODING ON HERBAGE YIELDS OF FOUR FORAGE SPECIES

(Yields of dry matter — grams per pot)

Crop	Temp. °F.	Period of flooding		
		7 days	14 days	21 days
Alfalfa	41	3.17	2.77	1.77
	54	3.79	2.40	1.87
	67	2.55	1.90	1.25
	80	2.32	1.82	1.22
Ladino clover	41	5.30	4.25	3.91
	54	3.60	4.72	4.52
	67	5.61	3.92	3.57
	80	1.92	2.62	3.85
Birdsfoot trefoil	41	5.12	3.52	2.32
	54	3.68	3.42	3.07
	67	4.62	3.00	3.50
	80	4.77	3.77	2.27
Brome grass	41	3.40	2.65	2.95
	54	3.00	2.91	2.93
	67	2.87	3.01	2.82
	80	2.72	3.10	3.37

Birdsfoot trefoil, unlike the other two legumes, showed remarkable resistance to flooding at the highest soil temperature. While the tendency was for decreased yields under longer periods of flooding, yields at the different temperatures were similar within a given period.

Brome grass yields decreased with increasing temperature during the 7-day period of flooding, but tended to increase slightly with increasing temperature for the 14- and 21-day period. This adaptability to the conditions imposed was similar to that of Ladino clover. Statistical comparisons of yields at different temperatures were not possible since there was no replication of temperature.

When the soil temperature was controlled, the yields of Ladino clover and of brome grass consistently increased with increased duration of flooding at the 80° temperature whereas they tended to decrease at the other temperatures. On the other hand, when the soil temperature was not controlled, the results indicated that the yields of grasses generally increased with increased moisture levels and duration of flooding whereas the yields of legumes tended to decrease.

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SOME CHEMICAL CHARACTERISTICS OF A SOLONETZIC SOIL SEQUENCE AT VEGREVILLE, ALBERTA, WITH REGARD TO POSSIBLE AMELIORATION

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ABSTRACT

Study of some of the chemical characteristics of the Duagh-Wetaskiwin-Malmo Solonetzic soil sequence at Vegreville, Alberta, reveals that the deep ploughing method of amelioration holds more promise than methods based on the application of commonly suggested amendments, e.g. gypsum, sulphur.

INTRODUCTION

Three groups of the Solonetzic Order occur on the Vegreville Sub-Station. They are the Solonetz (Duagh silt loam), the Solodized Solonetz (Wetaskiwin silt loam), and the Solod (Malmo silt loam); various intergrades can also be found. These soils occur in an irregular pattern on what would appear to be similar parent material. Consequently productivity varies considerably throughout the fields; the Solonetz has been the least productive and the Solod the most productive.

Various methods of improving Solonetzic soils have been advanced by Russian and American workers (1, 7). The methods are basically: ploughing to a 24-inch depth to incorporate gypsum and carbonates from lower horizons, the application of gypsum or sulphur, and the destruction of the tough B horizon. The present study was designed to chemically characterize a sequence having a very intractable Solonetz member, i.e., Duagh loam, in an effort to assess the possibilities of the aforementioned improvement practices, or the development of a substitute practice.

The general description of Solonetzic soils and the classical theory of their development were capably set forth by Bentley and Rost (2) and are not reviewed in this paper.

Soils Selected

Five sites were selected within a 500-foot transect to represent four levels of productivity based on visual examination of an established brome sod. Figure 1 shows the topography and areal distribution of the various sites. The root penetration and yield of forage are given in Table 1 for each site and its related soil type.

Each site shown in Figure 1 was sampled at two points, about 6 feet apart, to a 38-inch depth. These points were 3 feet north and 3 feet south of the transect line. The samples were taken partly on a horizon and partly on a depth basis. For example, the fragmented columns of the Malmo B horizon extend to a considerable depth without a distinct break at the B_3 horizon; thus the separation from the C horizon was arbitrarily made at 30 inches. The averaged sample depths and their horizon designations are shown in Figure 2 for the four soil types represented. The two sampling locations chosen to represent Wetaskiwin silt loam were only 6 feet apart. However, at one location the soil was a Wetaskiwin-Duagh

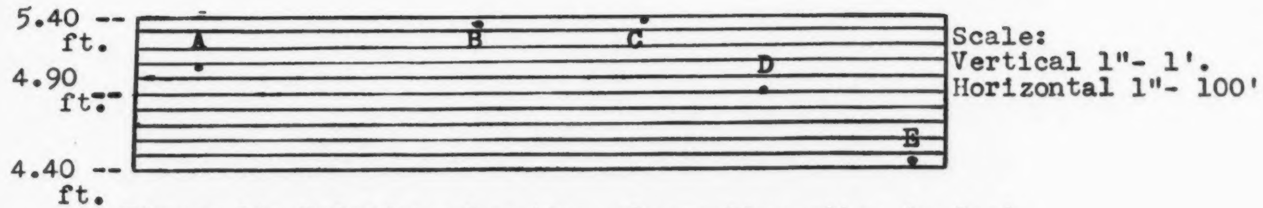

Figure 1A: Relative elevation of sampling sites in feet.

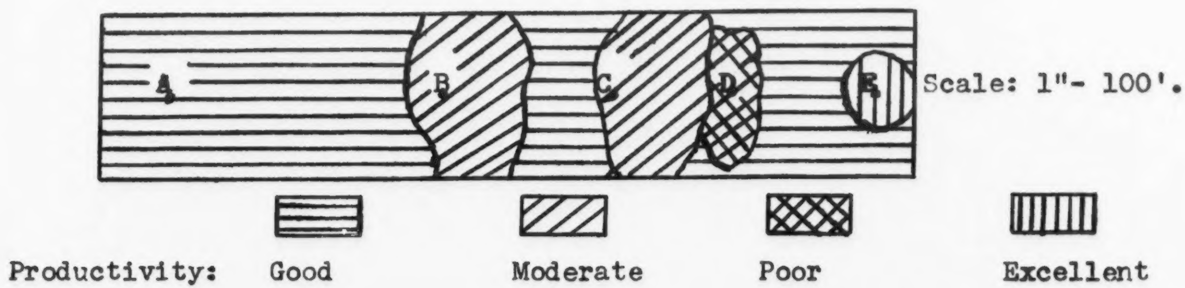

Figure 1B: Transect distribution of soils represented by sampling sites.

TABLE 1.—SOILS REPRESENTED BY SAMPLING SITES AND THE YIELD OF BROME AND THE ROOT PENETRATION

Sampling site	Soils[1]	Yield of dry hay/acre		Root penetration (in.)
		1958 (lb.)	1959 (lb.)	
A	Solonetz: Duagh loam			
	Solodized-Solonetz: Wetaskiwin loam	761	972	12-13
B	Solonetz: Duagh loam	675	836	8-9
C	Solonetz: Duagh loam	675	1062	8-9
D	Solonetz: shallow Duagh loam	220	746	7-8
E	Solod: Malmo loam	2246	3842	16-18

[1]In this paper classification is based on morphology (3, 4)

intergrade and at the other a Wetaskiwin-Malmo intergrade. The results of analysis and the subsequent discussion in this paper relate to soil type rather than the specific sampling location. However, sampling locations are also indicated in some tables where they seem to show the marked variability that occurs in these soils within short distances.

RESULTS OF CHEMICAL ANALYSIS

All chemical analyses were made according to methods set forth in U.S.D.A. Agriculture Handbook No. 60 (9) except the acid-soluble phosphate, which was extracted with .002N H_2SO_4 buffered with $(NH_4)_2SO_4$.

The quantity of anions does not precisely balance the quantity of cations determined in the saturation extract. Undoubtedly ions other than those determined are present, e.g. a concentration of soluble silica was found in the lime concentration horizon of two of the Duagh profile samples. Some of the general chemical characteristics are set forth in Table 2.

An extraction was performed with ammonium acetate, using a soil to extractant ratio of 1:25. In the absence of water soluble salts the difference between the quantity of bases extracted in this way and the quantity extracted with water represents exchangeable bases (9). However, where water-soluble salts occur in appreciable quantity, there is great doubt about this assumption (7, 9). For this reason, exchangeable bases are presented in this paper only for the surface soil samples. In general, salts are low in these samples. No assumption is made in the case of the other samples where carbonates, gypsum, and soluble salts are present. The quantity of cations is presented for these soils as extractable and represents the total quantity exchangeable plus soluble. The cations extractable with ammonium acetate are presented in Table 3 and the exchangeable cations in Table 4.

The total quantities of gypsum and carbonates were determined (9) and are shown in Table 5.

TABLE 2.—GENERAL CHEMICAL CHARACTERICTICS, PH, ORGANIC MATTER, SOLUBLE CONSTITUENTS

Soil	Location[1]	Horizon	Thick-ness, in.	pH	O.M. %	E.C. mmhos.	Saturation extract meq./100 gm.							Acid sol. P p.p.m.	S.A.R.[2]	E.S.P.[3]
							Cations				Anions					
							Ca	Mg	Na	K	HCO_3	Cl	SO_4			
Shallow	D	A_1	5	6.4	7.00	5.0	.38	.36	3.29	.03	.11	.09	3.88	47	20	20
Duagh	North	B_2	6	7.2	2.46	9.2	.40	1.38	7.28	.03	.08	.09	8.65	52	33	32
loam	and	B_3 & C		8.0	1.00	11.9	.86	2.13	12.71	.06	.07	.08	13.85	50	40	36
(Solonetz)	South	C		8.2	0.81	11.4	1.07	2.26	12.04	.06	.11	.08	13.69	88	35	34
Duagh	A South,	A_1	6	6.0	10.76	3.0	.08	.11	1.68	.03	.13	.06	1.65	67	23	24
loam	B and C	B_2	6	7.2	4.53	5.9	.26	.57	4.74	.04	.18	.07	5.57	68	27	28
(Solonetz)	North and	B_3 to C		7.8	1.49	15.9	.71	1.57	9.98	.06	.12	.05	11.30	79	35	33
	South	C		8.0	.99	14.8	.83	1.62	7.58	.06	.06	.04	10.15	83	28	29
Wetaskiwin	A	A_1	12	5.8	6.64	3.4	.04	.10	1.80	.00	.07	.02	1.62	42	28	30
loam	North	A_2	4	7.3	2.29	11.0	.90	1.47	9.30	.02	.03	.03	11.98	63	35	34
(Solodized-		B_2 & B_3	8	7.4	1.34	12.0	.49	2.05	10.03	.02	.10	.02	12.51	72	36	34
Solonetz)		C		7.8	1.15	11.2	1.08	1.93	15.40	.04	.09	.04	18.66	24	43	38
Malmo	E	A_1	8	6.1	16.09	1.1	.18	.14	0.12	.14	.10	.12	.42	177	1	0
loam	North	A_2 & A_3	10	6.2	4.12	1.0	.05	.07	0.14	.10	.07	.08	.18	114	5	5
(Solod)	and	B_2 & B_3	12	7.6	1.72	2.4	.10	.35	1.03	.01	.05	.15	1.35	15	12	14
	South	C1		7.7	1.23	2.8	.05	.28	1.18	.01	.06	.19	1.38	0	12	14

[1]Each site shown in Figure 1, i.e., A, B, etc., was sampled at two points 6 feet apart for chemical characterization. These points were North and South of the transect and are so designated
[2]S.A.R. — Sodium Adsorption Ratio
[3]E.S.P. — Exchangeable Sodium Percentage

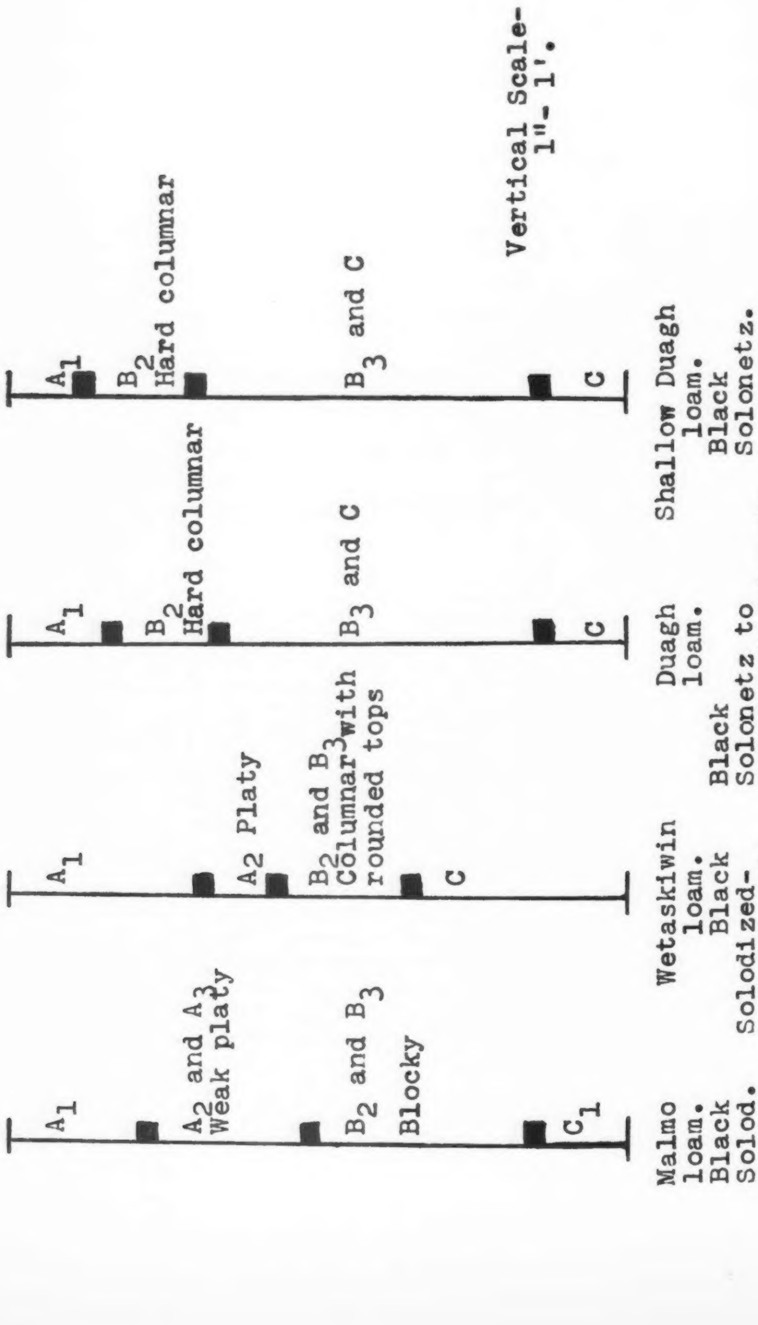

FIGURE 2. Profiles under study.

TABLE 3.—CATIONS EXTRACTABLE WITH AMMONIUM ACETATE

Soil	Horizon	Depth (in.)	Meq./100 gm.				Ratios			Na as % of total
			Ca	Mg	Na	K	Ca: Mg	Ca+ Mg: Na	Ca: Na	
Shallow Duagh 1	A_1	0-5	5.22	7.14	11.00	.80	.73	1.12	.47	45.5
	B_2	5-11	4.65	12.24	17.88	.99	.38	.94	.26	50.0
	B_3 & C	11-30	44.21	13.09	23.62	.82	3.38	2.43	1.87	28.9
	C	30-38	99.20	7.53	22.25	.76	13.17	4.80	4.46	17.2
Duagh 1	A_1	0-6	7.37	7.86	8.75	1.54	.94	1.74	.84	34.3
	B_2	6-12	5.43	11.32	17.15	1.31	.48	.98	.32	48.7
	B_3 & C	12-30	57.76	13.76	19.80	.94	4.20	3.61	2.92	21.5
	C	30-38	46.62	10.25	18.10	.79	4.55	3.14	2.58	23.9
Wetaskiwin 1	A_1	0-12	4.95	5.60	7.00	.30	.88	1.51	.70	39.2
	A_2	12-16	11.78	13.28	19.25	.62	.89	1.30	.61	42.8
	B_2 & B_3	16-24	31.55	13.28	20.50	.62	2.38	2.19	1.54	31.1
	C	30-38	45.23	16.32	27.50	.68	2.77	2.24	1.64	30.6
Malmo 1	A_1	0-8	25.08	7.90	1.12	3.42	3.17	29.45	22.39	3.0
	A_2 & A_3	8-18	13.30	4.01	1.75	3.10	3.32	9.89	7.60	7.9
	B_2 & B_3	18-30	51.12	7.30	5.25	.52	7.00	11.13	9.74	8.2
	C_1	30-38	42.48	5.34	5.00	.40	7.96	9.56	8.50	9.4

TABLE 4.—EXCHANGEABLE[1] CATIONS

			Per cent of metallic cations				Total	Ratios		
Soil	Horizon	Depth (in.)	Ca	Mg	Na	K	Meq./ 100 gm.	Ca: Mg	Ca+ Mg: Na	Ca: Na
Shallow Duagh 1	A_1	0-5	24.1	33.7	38.4	3.8	20.10	.71	1.51	.63
Duagh 1	A_1	0-6	30.9	32.8	29.9	6.4	23.62	.94	2.13	1.03
Wetaskiwin 1	A_1	0-12	30.9	34.6	32.7	1.9	15.91	89	2.00	.94
Malmo 1	A_1	0-8	67.4	21.0	2.7	8.9	36.94	3.21	32.66	24.90

[1]These data are determined as set forth in U.S.D.A. Handbook 60. However, it should be pointed out that there is some difference in the quantity of salts extracted by the water and ammonium acetate method, e.g., about 3 meq./100 g. more sulphate was removed from the A horizon of the Shallow Duagh with acetate than with water.

DISCUSSION OF DATA

General

The morphology of these soils, as shown in Figure 2, fits the classical definition (2, 7) very closely. Hard compact columns occur in the B horizon of the Duagh (Solonetz), rounded top columns occur in the B horizon of the Wetaskiwin (Solodized-Solonetz), and "disintegrated" columns in the B horizon of the Malmo (Solod).

The pH distribution is also typical of most Solonetzic soils in Alberta, with an acid A horizon over an alkaline B horizon.

As would be expected, the order of organic content is Malmo > Duagh > shallow Duagh. Wetaskiwin should fit between Malmo and Duagh; however it is lower. The fact that the A horizon of the Wetaskiwin is 12 inches deep as compared with 6 inches in the Duagh may satisfactorily explain its lower percentage value of organic matter.

TABLE 5.—THE DISTRIBUTION OF GYPSUM AND CARBONATES

Soil	Horizon	Depth (in.)	Gypsum meq./100 gm.	$CaCO_3$ equivalent[1] meq./100 gm.
Shallow Duagh 1	A_1	0-5	0	—
	B_2	5-11	0	—
	B_3 & C	11-30	7.2	20.8
	C	30-38	7.5	85.1
Duagh 1	A_1	0-6	0	—
	B_2	6-12	0	—
	B_3 & C	12-30	10.8	29.9
	C	30-38	5.3	56.1
Wetaskiwin 1	A_1	0-12	0	—
	A_2	12-16	2	—
	B_2 & B_3	16-24	8	25.2
	C	30-38	7	73.8
Malmo 1	A_1	0-8	0	—
	A_2 & A_3	8-18	0	1.8
	B_2 & B_3	18-30	0	102.0
	C_1	30-38	0	130.0

[1]This value may be somewhat high because of the reaction of other soil constituents with acid

Soluble Salts

There is an abundance of soluble salt in the profile of each soil except the Malmo. The predominant salt is sodium sulphate, with a lesser, but appreciable, quantity of magnesium sulphate. With increasing depth in all soils, other than Malmo, there is a rapid increase in the electrical conductivity of the saturation extract. The point where most crops suffer seriously from the lack of water (9) is reached at a 5-inch depth in the shallow Duagh, a 6-inch depth in the Duagh, and a 12-inch depth in the Wetaskiwin. Henkel (6) and others have referred to the shallow depth of soil from which plants can draw adequate water, and have stated that this is the cause of the frequent summer droughts that occur in Solonetzic soils. Farming these soils might be termed "flower-pot agriculture" because of the restricted soil from which plants can draw moisture.

The conductivity of the saturation extract of the surface soil is generally reasonably low. However, in the shallow Solonetz location, it would seem quite possible that the germination of many crops could be affected by the accumulation of salts in specific locations (9) termed slick spots. Indeed, in practice, crops quite often fail to germinate in these spots.

The occurrence of readily soluble salts above a layer of less soluble salts may indicate that sodium salts are still playing an active role in the development of these soils. In other words, if there were a positive downward movement of salts, the readily soluble salts should have essentially disappeared. It would appear that, assuming homogeneous parent material (approximately 10 feet of material deposited, by the Vermilion River, over till over Bearpaw shale), there has been a net, but very sluggish, downward movement of salts. These soils, other than the Solod, then are either poised in a state of resalinization, or are in the course of salinization that may occur at short intervals. Such a condition would have a critical bearing

on the effectiveness of deep ploughing and the duration of any benefit derived therefrom.

Much has been said about the relationship between topography and salt accumulation. Bentley and Rost (2) found the Solonetz, Solodized-Solonetz, Solod sequence occurring in either direction with regard to elevation. Henkel *et al.* (6) found the Solonetz to occur in micro depressions. This is quite true for the shallow Duagh soil under study, but it is extremely difficult to find a corresponding micro elevation to account for the very different salt status of the Malmo soil. This latter soil occurs in a very slightly depressed circle about 30 feet in diameter, surrounded by considerable areas of Duagh, and neither at the top nor the bottom of the general gentle slope to the east and north. There are very small islands of this soil spotted throughout the area. The micro-relief may have been altered slightly by cultivation, but it is difficult to conceive of it altering the general slope or removing all traces of elevations.

Acid Soluble Phosphate

There is a marked difference in the distribution of soluble phosphate. In the productive Malmo soil, it is concentrated near the surface, while in the less productive soils it generally increases slightly with depth. This distribution is in essential agreement with the findings of Dmitrenko and Shturmova (3), who offer an explanation based on plant uptake and deposition.

Extractable and Exchangeable Cations

The data show a somewhat similar situation to that revealed in the water extract data, but more clearly reveal the marked difference between the surface soil of the Malmo and the others, and the marked increase in calcium with depth.

The proportion of sodium to calcium and magnesium as indicated by the water-soluble salts data would appear to be deleterious in the A and B horizons of the soils other than the Malmo. In regard to the extractable cations, the Ca:Mg ratio is less than 1, the Ca + Mg:Na is less than 2, and the Ca:Na is less than 1, in the A and B horizons of the less productive soils. It is known that the latter two ratios are very undesirable (7, 9). Halstead *et al.* (5) found the Ca:Mg ratio to have little effect on plant growth. However, Kelley (7) gives considerable evidence indicating the possibility of magnesium toxicity. The occurrence of toxicity probably depends on many other nutritional factors, but it is interesting to note that the productive Malmo soil has a Ca:Mg ratio of 3.17:1 as compared with 1:1 in the others.

Distribution of Carbonates and Gypsum

There is essentially no gypsum or carbonate concentration within the first foot of soil. In the second foot there is a marked concentration, particularly of carbonates. There is no gypsum accumulation in the Malmo, and in this soil the carbonate concentration is somewhat deeper than in the others. There is a gypsum concentration in the second foot of the Solonetz and Solodized Solonetz soils, but here also the carbonates predominate

DISCUSSION OF RECLAMATION METHODS BASED ON SOME OF THE CHEMICAL CHARACTERISTICS OF THESE SOILS

Reclamation procedures, other than deep ploughing, are reviewed by Kelley (7). Deep ploughing is discussed in detail by various Russian workers (1, 8).

The Gypsum Method

Kelley (7) suggests that this method is not effective unless the soluble sodium is removed by leaching. He further suggests that a considerable quantity of irrigation water is usually required for its full effect. A 20-ton-per-acre application, costing $900.00, including freight, would supply only 11.60 milliequivalents of gypsum per 100 grams of soil. With 100 per cent efficiency, this would not completely remove the extractable sodium from the surface foot of soil. The low solubility of gypsum and the poor drainage of the soil, as indicated by the presence of soluble salts near the surface, would seem to eliminate this method of reclamation. Three years of trials at Vegreville have failed to show any benefit from the application of gypsum.

The Sulphur Method

This method is based on the reaction of sulphur with native calcium compounds. Native calcium, other than exchangeable, was not found in the surface foot of these soils. The application of sulphur should lower an already low pH and displace the calcium at present on the exchange. This treatment was tested and a 3-ton-per-acre application was found to lower the pH to 3.3. Germination of cereals was completely eliminated on these areas. It would not seem reasonable that an acid treatment should prove desirable.

The Deep Ploughing Method

With this method there are two major points to consider: the possibility of success, and the depth of ploughing required. In these considerations, thorough mixing of the soil to the depth ploughed will have to be assumed.

Ploughing to a 1-foot depth would, in the main, not elevate any native gypsum or carbonate, but would elevate more sodium. It would destroy some of the massive B horizon, but it would seem probable that the increase in sodium would offset any benefit from mechanical disturbance. There would also be some loss of the benefit of a developed A horizon.

Ploughing to an 18-inch depth would elevate approximately 6 tons of gypsum and 10 tons of $CaCO_3$ equivalent per acre in the shallow Duagh, 9 tons of gypsum and 15 tons of $CaCO_3$ equivalent in the Duagh, and 4 tons of gypsum in the Wetaskiwin. The top acre foot of the Duagh soils would then be treated with about the calcium equivalent of a 20-ton-per-acre application of gypsum, if the carbonate is predominantly calcium. There would, of course, be a substantial elevation of sodium salts. These should leach more rapidly than the calcium, and at any rate the ratio of Ca:Na as indicated in Table 2 would be improved.

Ploughing to a 24-inch depth would result in the elevation of 12 tons of gypsum and 20 tons of $CaCO_3$ equivalent per acre in the shallow Duagh, 18 tons of gypsum and 30 tons of $CaCO_3$ equivalent in the Duagh, and 9 tons of gypsum and 16 tons of $CaCO_3$ in the Wetaskiwin. Since most of the soil is Duagh, the approximate value of this ploughing in terms of gypsum cost would be over $2,000.00 per acre. In addition to the value of carbonates and gypsum, the clay elevated should be essentially Ca or Ca + Mg saturated.

According to Antipov-Karataev (1) the success of this method depends on the mobilization of the carbonates. He states that the reactions involved are as follows:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2 \quad (1)$$

$$2\ Na\text{-}soil + Ca(HCO_3)_2 \rightarrow Ca\text{-}soil + 2\ NaHCO_3 \quad (2).$$

The reactions are dependent on the production of carbonic acid from the organic matter of the A horizon that has been intimately mixed with the carbonates.

There are not very many data on the carbonate content of Russian Solonetzic soils improved by deep ploughing, but Antipov-Karataev (1) does present data showing an apparently higher content than those under study here.

The B horizon should be completely destroyed by ploughing 18 to 24 inches deep. This could allow the leaching required to lower the sodium content in the surface layer of soil.

There would also be a damaging effect on the already very productive Malmo. Indeed, there would be some loss of organic matter in all members. The damage to the Malmo would probably not be too serious, since there is very marked root concentration to an 18-inch depth. It may be assumed that soil to this depth is a satisfactory medium for plant growth. Antipov-Karataev (1) does emphasize the need for fertilizers and manures after ploughing.

In a greenhouse study at Vegreville there was up to ten times as much growth of wheat in pots where the A and the lime-salt horizons of the Duagh soil were mixed in equal quantities, than where the A horizon alone was the growth medium. This study has not progressed to the point where the cause of this can be clearly stated. These preliminary results are presented, because they relate very closely to the deep ploughing method of amelioration.

A plough capable of ploughing 20 inches deep, when mounted on a Killifer Chisel, was constructed for about $200.00 and used in the fall of 1959 on these soils. A commercial plough would cost considerably more. Assuming a caterpillar tractor moving 3 miles per hour, costing $10.00 per hour, and turning a furrow 18 inches wide, the cost would be less than $20.00 per acre. With a two-bottom plough the operating cost would be further reduced. This relatively low cost indicates a need for serious field trials of the method.

CONCLUSIONS

1. The Duagh-Wetaskiwin-Malmo Solonetzic soil complex is morphologically typical of Solonetzic sequences reported in the literature, but the Solonetz member is somewhat higher in soluble salt content in the A horizon than others reported.

2. Deep ploughing to at least 18 inches and probably to 24 inches offers more hope than the other commonly suggested ameliorative practices, e.g., sulphur, gypsum, etc., on the Duagh-Wetaskiwin-Malmo Solonetzic soil complex.

3. The migrations of soluble salts and the effect of such migrations need further study, as do the general moisture characteristics.

ACKNOWLEDGEMENT

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INJURIOUS EFFECTS OF FERTILIZERS APPLIED WITH THE SEED ON THE EMERGENCE OF FLAX

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ABSTRACT

Several fertilizer formulations were placed with the seed of Rocket flax at various rates to observe their effects on emergence.

In field tests, 20 pounds of nitrogen per acre placed with the seed significantly reduced emergence. When broadcast, 80 pounds caused no reduction in stand, and yields were increased. Whenever the fertilizer treatments reduced the stand of flax to 43 plants per foot of row or less, yields were reduced. This number of plants corresponds to a seeding rate of approximately 36 pounds per acre.

In greenhouse tests it was generally safe to apply up to 15 pounds of nitrogen with flax seed if soil moisture was adequate. P_2O_5 in the form of mono-ammonium phosphate could be safely applied at rates from 5 to 20 pounds, depending on the $N:P_2O_5$ analysis of the fertilizer. The greater the amount of N in the fertilizer, the less P_2O_5 could be used. Results with mono-calcium phosphate were more erratic and generally less satisfactory than with mono-ammonium phosphate. The former could not be used safely at rates above 15 pounds P_2O_5 per acre.

Damage to flax from commercial fertilizers was greater when the moisture content of the soil was low. The results indicated that fertilizers at normal rates should not be applied in close contact with flax seed unless there is adequate moisture for germination and growth.

INTRODUCTION

It is well established that commercial fertilizers applied in close contact with the seed can damage crops, either by toxic action of some fertilizer elements or by increased osmotic pressure of the soil solution. Observational data suggest that flax may be damaged by placing moderate amounts of fertilizers with the seed at planting time. In Saskatchewan, 11-48-0 is currently recommended for flax on summerfallow at the rate of 30 pounds per acre. However, as far as the author is aware, the amount of fertilizer that can be applied safely with flax seed has not been determined.

Damage to garden crops by placing fertilizers in contact with the seed at planting time has been reported (1, 4, 9). Truog *et al.* (11) found that legumes seeded with small grains were damaged by such treatment. Several others (3, 6, 9, 10) have advised against placing fertilizers in close contact with the seeds of various garden and field crops.

Olson and Dreier (8) reported severe stand reduction and yield losses as a result of applying moderate rates of N and K with the seed of small grains in Nebraska. The losses were not uniform from year to year, nor in a single year in different parts of the State. Damage was also more severe at low soil moisture levels. The reduction in stand under limiting moisture conditions was apparent at 10 pounds N per acre. Applying P_2O_5 with the seed of small grains was desirable in drier regions as long as the N concurrently added with the seed did not exceed 10 or 15 pounds per acre. Wheat and barley were damaged more than oats or rye.

Dubetz *et al.* (5) studied the effect of five fertilizer treatments on the germination of canning corn, field beans and sugar beets at three moisture

levels. They found that "moisture levels had no significant effect on germination of any of the crops. Moisture levels in combination with nitrogen fertilizers reduced germination, and the reduction became progressively pronounced with decreasing moisture. Nitrogen caused a greater reduction than manitrol or P_2O_5." "Results indicate that no fertilizer should be placed in contact with bean seeds", and "ammonium nitrate should not be placed in contact with corn or beet seeds when soil moisture is limiting."

This paper is a report of experiments conducted at Regina to study the effect on flax emergence of various amounts and formulations of fertilizer applied with the seed.

MATERIAL AND METHODS

The experiments which are reported here were conducted on soil described by Mitchell *et al.* (7) as Regina heavy clay generally containing about 56 per cent clay, 32 per cent silt and 12 per cent sand. The field moisture capacity is approximately 40 per cent and the wilting point 20 per cent. The pH is close to 7.5 on the average, according to Clayton *et al.* (2).

In 1956 and 1957 experiments comparing the placement of ammonium nitrate fertilizer (33.5-0-0) with the seed and above the seed were made on rod row plots of Rocket flax in the field. The seeding rate was 60 pounds per acre. The fertilizers were applied with the seed using a double disk drill. When placed above the seed the fertilizer was broadcast over the plots after seeding and raked into the soil. In 1956, rates of 0, 20, 40 and 80 pounds N per acre were tested. In 1957, the rates were similar, except that a 30-pound treatment was added. Yields were recorded in both years, and plant counts per foot of row were made in 1957. Field tests in both years were made on stubble land.

In greenhouse tests, summerfallow soil was sifted through a 14-mesh screen and mixed with 0.2 per cent Krilium by weight. Sufficient water was applied in a fine spray to the air-dried soil to bring the moisture content to 2 per cent above the desired levels of 26 and 35 per cent. The former is considered to be the minimum required to support germination and growth, the latter is about optimum in this respect.

The moistened soil was placed in wooden flats to a depth of 4 inches. Rocket flax was sown 1 inch deep in rows 6 inches apart. The seeds were placed 1 inch apart in the row, and granular fertilizer was spread uniformly in the row with the seed. After planting, the flats were placed in the greenhouse and covered with polyethylene sheets to reduce evaporation. The flats were not watered at any time after planting. Soil moisture was determined at the initiation and completion of each test. Average measurements for the 3-week growing period were 26.3 and 35.9 per cent in 1958 and 25.9 and 33.7 per cent in 1959. These were reasonably close to the objectives of 26 and 35 per cent.

Rate of emergence, total emergence 3 weeks after planting and dry weight of seedlings were recorded.

Fertilizers and rates tested in the greenhouse in 1958 and 1959 are listed in Tables 3, 4 and 5. The treatments were replicated five times in

1958 and four times in 1959, and analysed as randomized blocks, using Duncan's multiple range test of significance. In the remainder of this paper these fertilizers will be frequently designated by their $N\text{-}P_2O_5\text{-}K_2O$ analysis.

RESULTS AND DISCUSSION

Field Trials

The effect of method of fertilizer application on flax yield is shown in Table 1.

When placed with the seed, 20 pounds of N increased the yield of flax by 3.9 bushels per acre. As the rate of N was increased the yield increase became less until at 80 pounds of N the yield was depressed by 1.4 bushels per acre. Fertilizer placed above the seed increased yields substantially. The 80-pound rate increased the yield by 11.1 bushels over the check, but, what is more important, it increased the yield by 12.5 bushels over the yield where fertilizer was placed in contact with the seed.

In the 1957 field trials, the effect of fertilizer placement on emergence and yield of flax, grown on stubble, was studied. The results are presented in Table 2.

TABLE 1.—EFFECT OF FERTILIZER ON YIELD OF ROCKET FLAX SOWN ON STUBBLE, 1956

Fertilizer treatment[1] as ammonium nitrate 33.5-0-0	Yield—bushels per acre	
	Fertilized with seed	Fertilized above seed
No additional N (check)	11.5	11.5
20 lb. N per acre	15.4	16.5
40 lb. N per acre	13.7	15.9
80 lb. N per acre	10.1	22.6**

**Significantly higher than check
[1]In addition to the N applied as 33.5-0-0, all plots received 43 pounds 11-48-0 per acre with the seed

TABLE 2.—EFFECT OF FERTILIZER PLACEMENT ON EMERGENCE AND YIELD OF FLAX GROWN ON STUBBLE, 1957

Fertilizer treatments P_2O_5 applied as 0-45-0 and N as 33.5-0-0		Placement	Plants per foot of row	Yield of flax bushels/acre
P_2O_5 lb./ac.	N lb./ac.			
0	0		70.7	17.3
40	80	With seed	17.7**	12.4**
40	30	With seed	36.4**	15.4
20	40	With seed	43.5**	16.1
0	20	With seed	51.6*	17.4
0	30	Broadcast	59.8	17.4
20	40	P_2O_5 with seed N broadcast	66.9	17.1
0	80	N broadcast	72.2	16.6

*Significantly lower than the check at 5% level
**Significantly lower than the check at 1% level

TABLE 3.—EFFECT OF COMMERCIAL FERTILIZERS APPLIED WITH THE SEED ON EMERGENCE OF FLAX IN THE GREENHOUSE, 1958

Fertilizer	Analysis	Rate of application	Soil moisture 35%		Soil moisture 26%	
			Days emergence delayed	Emergence % of check	Days emergence delayed	Emergence % of check
		lb. P_2O_5				
Mono-ammonium phosphate	11-48-0 @	15	0.0	102.1	0.0	100.0
		30	0.5	80.9	0.0	85.4
		60	1.0	68.1*	0.5	45.8**
Mono-calcium phosphate	0-45-0 @	15	1.0	88.5	0.5	71.2*
		30	0.0	73.1*	1.0	69.2*
		60	1.0	51.9**	2.0	44.2**
Mono-ammonium phosphate sulphate	16-20-0[1] @	15	0.0	106.8	0.0	63.6
		30	0.5	93.2	0.0	27.3
		60	1.0	25.0**		0.0
Mono-ammonium phosphate and ammonium nitrate	27-14-0[1] @	15	2.0	72.2*	1.0	15.8**
		30	4.0	22.2**	2.0	5.3**
		60	2.0	5.6**	2.0	5.3**
		lb. N				
Ammonium nitrate	33.5-0-0 @	15	0.5	110.9	1.5	58.8**
		30	2.0	82.6	2.0	25.5**
		60	2.0	28.3**		0.0**
Ammonium sulphate	21-0-0[1] @	15	0.5	104.5	2.5	17.4**
		30	2.0	72.7	0.5	8.7**
		60	4.0	11.4**		0.0**

*Significantly lower than the check at the 5% level
**Significantly lower than the check at the 1% level
[1]In the tests with these three fertilizers, the emergence of untreated checks was significantly lower with 26% than with 35% soil moisture

Large decreases in the number of plants per foot of row occurred from treatments where fertilizers were placed with the seed. Significant reductions did not occur where the nitrogen was broadcast. A yield decrease, though not significant, occurred with 43.5 plants per foot of row, which is equivalent to a seeding rate of 36 pounds per acre. This is in agreement with previous work at Regina where flax yields decreased as seeding rate was decreased below 40 pounds per acre*. The lack of yield increases from the fertilizer treatments was attributed to the unusually dry season. Soil moisture reserves were low at seeding time, and precipitation was below normal for the period May to September inclusive.

Greenhouse Tests

In 1958 greenhouse tests were designed to compare the effect of various kinds and amounts of commercial fertilizer on the emergence of flax when placed with the seed. Six different fertilizers were tested at two soil moisture levels. Emergence data are shown in Table 3.

At the higher moisture level there was no significant injury to emergence from 30 pounds of P_2O_5 applied as 11-48-0 or 16-20-0. Similar rates of 0-45-0 and the 15-pound rate of 27-14-0 reduced emergence significantly. Considering both moisture levels, nitrogen fertilizers were more damaging than phosphate fertilizers. Similarly 0-45-0 and 16-20-0 were more damaging than 11-48-0, and ammonium sulphate was more damaging than ammonium nitrate. In general, injury increased with decreased soil moisture. Delays in emergence of 2 days or more occurred with 27-14-0, 33.5-0-0 and 21-0-0 at rates of 30 pounds of N per acre or higher. Differences in average dry weight of seedlings were not significant and for this reason are not included in the table.

The 1959 tests were designed to provide further information on the effect of rates of various fertilizers on emergence of flax. In addition comparisons of different ratios of N to P_2O_5 were made using ammonium nitrate as the source of N and calcium phosphate as the source of P_2O_5. Results are shown in Tables 4 and 5.

Forty pounds per acre of P_2O_5, applied as 11-48-0, did not affect emergence under optimum moisture conditions. On the other hand, 40 pounds of P_2O_5, applied as 16-20-0, showed a significant reduction in emergence. It appears, therefore, that the 30-pound rate as shown by the 1958 results is a safe level of treatment for 16-20-0. The results with 0-45-0 were in conflict with the results obtained in 1958. Whereas 40 pounds of P_2O_5 caused no significant reduction in emergence in 1959, 30 pounds gave a greater reduction in 1958. Since the fertilizer was from the same source in both years, no explanation, other than experimental variability, can be offered at this time. However, because of the damage incurred in 1958, rates above 30 pounds per acre do not appear to be acceptable. This conclusion is based on limited data and further work is needed to clarify the situation.

**Author's unpublished data*

TABLE 4.—EFFECT OF COMMERCIAL FERTILIZERS APPLIED WITH THE SEED ON EMERGENCE OF FLAX IN THE GREENHOUSE, 1959

Fertilizer	Analysis	Rate of application	Soil moisture 35%	
			Days emergence delayed	Emergence % of check
		lb. P_2O_5		
Mono-ammonium phosphate	11-48-0 @	10	0.8	100.0
		20	0.3	110.5
		40	0.0	94.7
		80	0.0	57.9*
Mono-calcium phosphate	0-45-0 @	10	0.0	105.2
		20	0.0	107.7
		40	0.0	81.5
		80	0.9	63.2*
Mono-ammonium phosphate sulphate	16-20-0 @	10	0.7	113.2
		20	1.8	84.2
		40	1.8	63.2*
		80	0.8	15.8**
		lb. N		
Mono-ammonium phosphate and ammonium nitrate	27-14-0 @	5	0.8	105.2
		10	0.0	97.4
		20	0.9	73.7
		40	3.1	60.5*
Ammonium nitrate	33.5-0-0 @	5	0.8	110.5
		10	0.9	110.5
		20	2.3	89.5
		40	2.9	42.1**

*Significantly lower than the check at 5%
**Significantly lower than the check at 1%

Because severe damage was experienced at all rates in 1958, lower applications of 27-14-0 were substituted the following year. Twenty pounds of N, in the form of 27-14-0, did not show a significant reduction in emergence of flax. Similar results were obtained with 33.5-0-0. Since the 40-pound rates of these two fertilizers caused significant reductions in emergence it might be assumed that the 20-pound rate of 27-14-0, and the 30-pound rate of 33.5-0-0, as tested in 1958, are safe levels of application with flax seed under optimum moisture conditions. Under conditions of limiting moisture, damage was usually more severe and results were inconsistent, and for this reason are not presented here. Under moist conditions rates of N, up to 20 pounds per acre, caused delays in emergence of 1 to 3 days. With few exceptions, which occurred with rates of 40 pounds of N or 80 pounds of P_2O_5, differences in dry weight of seedlings were not significant.

Table 5 shows the effect of varying amounts and proportions of N and P_2O_5 on emergence of flax. The data for 0-45-0 and 33.5-0-0 are carried over from Table 4 so that they can be readily compared with results from different combinations of these two fertilizers.

TABLE 5.—EFFECTS OF VARYING AMOUNTS AND PROPORTIONS OF N AND P_2O_5 APPLIED WITH THE SEED ON EMERGENCE OF FLAX IN THE GREENHOUSE, 1959

Fertilizer treatment		Soil moisture 35%	
Ammonium nitrate 33.5-0-0 lb. N per acre	Calcium phosphate 0-45-0 lb. P_2O_5 per acre	Days emergence delayed	Emergence % of check
0	0 (check)	—	100.0
5	0	0.8	110.5
10	0	0.9	110.5
20	0	2.3	89.5
40	0	2.9	42.1**
0	10	0.0	105.2
5	10	0.0	76.8
10	10	0.7	63.2*
20	10	2.9	76.8
40	10	3.0	42.1**
0	20	0.0	107.7
5	20	0.0	81.5
10	20	0.3	71.0
20	20	2.4	81.5
40	20	3.5	39.5**
0	40	0.0	81.5
5	40	0.0	76.3
10	40	0.0	63.2*
20	40	1.5	52.6*
40	40	3.5	44.7**
0	80	0.9	63.2*
5	80	0.8	36.8**
10	80	0.4	31.6**
20	80	1.3	13.2**
40	80	0.0	2.6**

*Significantly lower than the check at 5 per cent level
**Significantly lower than the check at 1 per cent level

Rates of 10 pounds per acre of N, applied as ammonium nitrate, or 20 pounds of P_2O_5 in the form of mono-calcium phosphate, had no apparent effect on emergence at the 35 per cent moisture level. Without exception, all combinations of N and P_2O_5 showed reductions in emergence at both moisture levels, although some of these reductions were not significant. Eighty pounds of P_2O_5 reduced emergence severely, the injurious effect becoming much more pronounced with the addition of small amounts of N. Forty pounds of N in combination with eighty pounds of P_2O_5 permitted less than 3 per cent emergence.

In view of the inconsistencies obtained from the use of 0-45-0 in 1958 and 1959, and the tendency in the 1958 tests for more damage from 0-45-0 than from 11-48-0 at equal rates of P_2O_5, a comparison was made of these two fertilizers when applied at approximately equal rates of both N and P_2O_5. Ammonium nitrate (33.5-0-0) was mixed with 0-45-0 to make the proportion of N to P_2O_5 equal to that of 11-48-0. The data, as presented in Table 6, are extracted from Tables 4 and 5.

The first two combinations were safely applied with the seed where ammonium phosphate was used as the P_2O_5 carrier. In addition, all three ammonium phosphate treatments were superior to their counterparts in

TABLE 6.—COMPARISON OF THE EFFECTS OF TWO PHOSPHATE CARRIERS ON EMERGENCE OF FLAX IN THE GREENHOUSE, 1959

Approximate amounts of N and P_2O_5 per acre		Emergence—% of check	
		Ammonium phosphate 11-48-0	Calcium phosphate and ammonium nitrate 0-45-0 and 33.5-0-0
lb. N	lb. P_2O_5		
5	20	110.5	81.5
10	40	94.7	63.2*
20	80	57.9*	13.2**

*Significantly lower than the check at the 5% level
**Significantly lower than the check at the 1% level

TABLE 7.—MAXIMUM AMOUNT OF COMMERCIAL FERTILIZERS THAT CAN BE SAFELY APPLIED WITH FLAX SEED UNDER FAVOURABLE MOISTURE CONDITIONS

Carrier	Analysis	Fertilizer lb./acre	N lb.	P_2O_5 lb.
Calcium phosphate	0-45-0	30	—	15
Ammonium phosphate	11-48-0	40	5	20
Ammonium phosphate sulphate	16-20-0	75	12	15
Ammonium phosphate and ammonium nitrate	27-14-0	35	10	5
Ammonium nitrate	33.5-0-0	60	20	—
Ammonium sulphate	21-0-0	70	15	—

calcium phosphate. The 1958 data in Table 3 indicate that calcium phosphate caused more damage to flax seedlings than ammonium phosphate when applied at 30 pounds of P_2O_5 per acre or more. However, the 1959 results (Table 4) show no difference between these two fertilizers. When ammonium nitrate was added to calcium phosphate (Table 6) the damage was much more severe than that obtained from the use of ammonium phosphate at equal rates of N and P_2O_5. Since the calcium phosphate was no more deleterious than ammonium phosphate in the 1959 tests, the increased damage from the calcium phosphate-ammonium nitrate mixture must have been due to the addition of ammonium nitrate or the interaction of nitrogen and phosphorus.

Further work is needed to determine whether or not P_2O_5 in the form of 0-45-0 is more harmful than equivalent amounts in the form of 11-48-0 when placed in contact with the seed.

Under the conditions of these experiments the maximum amounts of commercial fertilizer which can be safely applied with flax seed under favourable moisture conditions are listed in Table 7.

It appears that P_2O_5 in the form of calcium phosphate can be applied safely with the seed at rates as high as 15 pounds per acre. Similarly, nitrogen applied as ammonium nitrate or sulphate can be used at rates up to 20 and 15 pounds per acre, respectively. Where N and P_2O_5 are com-

bined, as in 11-48-0, amounts of N as low as 5 pounds per acre permit rates as high as 20 pounds of P_2O_5. On the other hand, where N and P_2O_5 are combined, as in 16-20-0 and 27-14-0, increasing the proportion of N to P_2O_5 results in greater damage to emerging seedlings than does N alone, and at the same time reduces the safe level of P_2O_5. Larger amounts of fertilizer will give very beneficial effects if broadcast after seeding.

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EFFECT OF SOIL TYPE, SOIL MOISTURE, AND NITROGEN FERTILIZER ON THE GROWTH OF SPRING WHEAT[1]

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ABSTRACT

Spring wheat was grown in the greenhouse on two soil types with nitrogen rates of 0, 30, 60, and 90 pounds per acre and at three moisture levels. Significant increases in yield of grain and significant decreases in percentage protein were obtained with increasing soil moisture on a loam soil but not on a loamy sand. Apparently, the difference in plant growth between soils may be attributed to the greater changes in moisture tension of the loam soil within the moisture ranges studied. The loam soil was also watered less frequently and the high moisture tensions were of longer duration.

Both soils showed significant increases in yield of grain with increasing nitrogen fertilizer, but significant increases in percentage protein were obtained on the loam soil only. The largest yield increase per unit of nitrogen was obtained on the loamy sand. The growth of wheat on the loam soil was significantly superior in all respects except for the roots to that on the loamy sand. This is explained on the basis of differences in the original fertility of the two soils before treatment.

INTRODUCTION AND LITERATURE REVIEW

Veihmeyer and Hendrickson (10), working with tree fruits, proposed that water is equally available to plants over the entire range from field capacity to the permanent wilting percentage. This concept appears to have been fairly well refuted by the evidence shown in the reviews of Richards and Wadleigh (8) and Black (2). Hagan *et al.* (4) showed that various processes of Ladino clover responded differently to high and low moisture levels within the available soil moisture range.

Results of work conducted in southern Alberta[2] showed that under irrigation the protein content of spring wheat decreased with increasing nitrogen fertilizer. Russell *et al.* (7) reported that on dry land the protein content of wheat usually increased with nitrogen fertilizer. Fernandez and Laird (3) grew wheat under various moisture and nitrogen fertilizer treatments in Mexico. They reported that, whereas yields increased when both moisture and nitrogen fertilizer increased, the protein content decreased with increasing soil moisture and increased with nitrogen applications of over 45 pounds per acre.

The literature review shows that yield and protein responses vary with different nitrogen and moisture levels. This paper reports the effects of the three variables, soil type, soil moisture, and nitrogen fertilizer, upon the yield and protein content of spring wheat.

MATERIALS AND METHODS

The experiment was carried out in the greenhouse with two soil types, three moisture levels, and four nitrogen treatments. The design was a 2 x 3 x 4 factorial with three blocks per replicate and with the second order interaction completely confounded in each of four replicates.

The two soil types were:

1. *Loam* – Lethbridge series (Leth.) from near Lethbridge
2. *Loamy sand* – Cavendish series (Cd.) from near Fincastle.

[1]Contribution from the Soils Section.

[2]*Unpublished data.* Annual report, Experimental Station, Lethbridge, Alta. 1954.

The moisture levels were as follows:

1. Field capacity to ¾ of field capacity
2. Field capacity to ½ of field capacity
3. Field capacity to ¼ of field capacity.

The nitrogen treatments using ammonium nitrate (33.5-0-0) fertilizer as the source consisted of:

1. Check – no nitrogen
2. 30 pounds of N per acre
3. 60 pounds of N per acre
4. 90 pounds of N per acre.

The field capacity and permanent wilting percentage were 23.3 and 8.8 for the loam soil and 15.2 and 5.2 for the loamy sand. The field capacity and permanent wilting percentage were determined by the methods of Lehane and Staple (6, 5). The soils were treated with soil conditioner (Krilium, 0.05 per cent of soil weight) to preserve their physical condition. Two-gallon glazed crocks were used, which held approximately 20 pounds of loam or 25 pounds of loamy sand. To ensure maximum crop growth, triple superphosphate (0-43-0) at the rate of 30 pounds of P_2O_5 per acre was applied to all crocks. All of the fertilizer treatments were spread uniformly on the surface and then worked into the top half-inch of soil.

Twenty seeds of Thatcher wheat treated with a fungicide were planted in each crock. Upon emergence the plants were thinned to 10 per crock.

The surface soil in the crocks was kept moist for the first 10 days after seeding. Following this period the soil in all the crocks was brought to field capacity. Throughout the remainder of the experiment the crocks were weighed daily and when one-quarter, one-half, or three-quarters of the available moisture in the respective series was depleted, the soil was brought to field capacity.

At harvest time the number of heads of wheat per crock and the mean height of plants were recorded. The heads were allowed to dry for 3 weeks prior to threshing. Air-dry weights of threshed grain and straw were recorded. In addition, the soil was washed away from the roots and, subsequently, air-dry weights were taken. The nitrogen content of the grain was determined by the Kjeldahl method (1) and was converted to protein with the factor 5.7.

RESULTS AND DISCUSSION

Table 1 shows mean data per crock for height of grain, number of heads, weights of grain, straw, and roots, percentage protein, and total protein in grain, at different moisture levels for each soil. In both soils the wheat was significantly taller at the highest moisture level than at the lowest level. The number of heads, weight of grain, and weight of straw of wheat grown in the loam soil were significantly increased with each increase in moisture level, while in the loamy sand significant increases in the number of heads and in straw yield between the lowest and highest moisture levels were obtained.

TABLE 1. — EFFECT OF THREE MOISTURE LEVELS ON SPRING WHEAT GROWN ON TWO SOILS (MEANS PER CROCK CALCULATED FROM FOUR REPLICATES AND FOUR NITROGEN LEVLES)

	Loam			Level of significance[1]	Loamy sand			Level of significance[1]	Mean		Level of significance[1]
	Moisture level				Moisture level						
	¼	½	¾		¼	½	¾		Loam	Loamy sand	
				per cent				per cent			per cent
Height of wheat — inches	40	43	44	1	39	40	41	1	42	40	1
Number of heads	12	14	19	1	10	12	12	1	15	12	1
Weight of grain — grams	13.1	15.4	16.8	5	10.0	10.5	10.8	5	15.1	10.4	1
Weight of straw — grams	17	22	26	1	13	15	17	1	21	15	1
Weight of roots — grams	4	4	6	5	5	5	4	5	5	5	5
Protein in grain — per cent	12.9	11.2	10.4	5	10.9	10.6	10.7	5	11.5	11.1	1
Total protein — grams	1.69	1.73	1.73	5	1.07	1.09	1.13	5	1.72	1.10	1

[1]Any two means underscored by the same line are not significantly different at the levels indicated

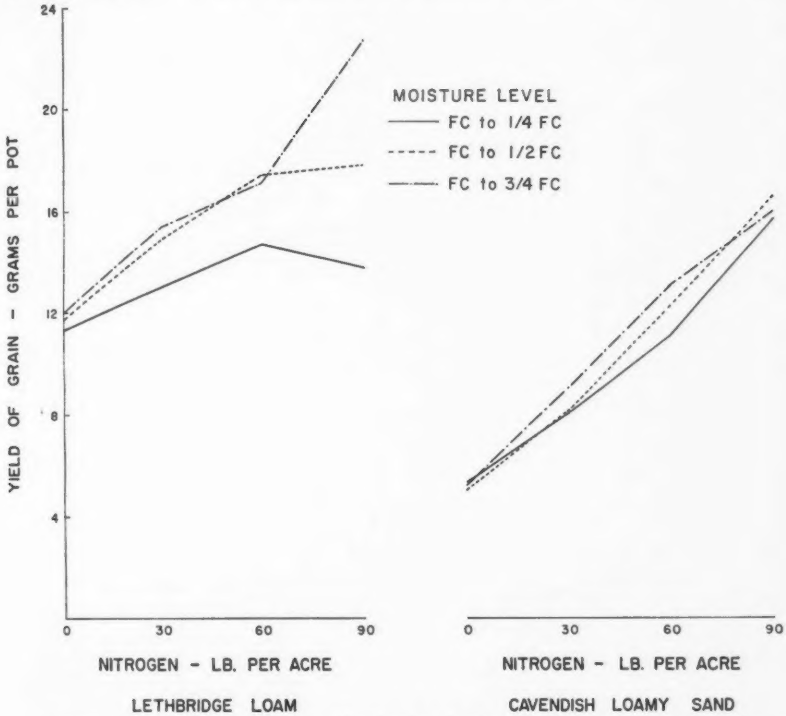

FIGURE 1. Effect of four levels of nitrogen on the yield of spring wheat at three moisture levels for two soils.

Significant decreases in the percentage protein of grain were obtained with increasing moisture levels in the loam soil but not in the loamy sand. There were no significant differences in the weights of roots nor in the total production of protein in the grain between moisture levels of either soil.

There was less difference in plant growth between moisture levels in the loamy sand soil because coarse-textured soils exhibit less change in moisture tension (9), within the moisture ranges studied, than that exhibited by finer-textured soils. Also, the coarser soil was watered more frequently so that the higher moisture tensions were of shorter duration in this soil.

The effect of levels of nitrogen on the growth characteristics of spring wheat is shown in Table 2. The height of wheat was significantly increased with nitrogen fertilizer on the loamy sand but not on the loam soil. The number of heads of wheat per plant was significantly increased with the highest nitrogen rate on the loamy sand and with the two highest rates on the loam soil. The weight of grain on both soils increased significantly with increasing levels of nitrogen. While significant increases in the weight of straw by nitrogen fertilizer were observed in both soils, an increase in root weight was shown in the loamy sand soil only.

TABLE 2. — EFFECT OF FOUR LEVELS OF NITROGEN ON SPRING WHEAT GROWN ON TWO SOILS (MEANS PER CROCK CALCULATED FROM FOUR REPLICATES AND THREE MOISTURE LEVELS)

	Loam				Level of significance[1]	Loamy sand				Level of significance[1]
	lb. nitrogen per acre					lb. nitrogen per acre				
	0	30	60	90		0	30	60	90	
					per cent					per cent
Height of wheat — inches	42	43	43	42	1	32	40	44	43	1
Number of heads	12	14	18	17	1	10	10	12	15	1
Weight of grain — grams	11.7	14.3	16.3	18.0	1	5.2	8.4	12.0	16.0	1
Weight of straw — grams	16	20	24	25	1	7	12	18	23	1
Weight of roots — grams	4	5	5	5	1	2	5	7	6	1
Protein in grain — per cent	10.7	10.8	11.6	12.8	5	11.6	10.6	10.5	10.2	5
Total protein — grams	1.25	1.53	1.88	2.21	1	0.60	0.89	1.26	1.64	1

[1]Any two means underscored by the same line are not significantly different at the levels indicated

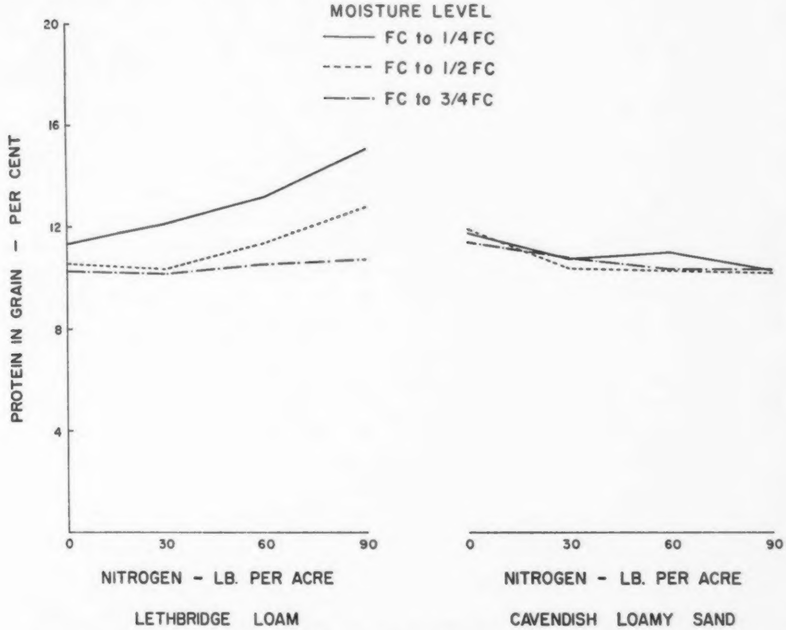

FIGURE 2. Effect of four levels of nitrogen on the percentage protein of spring wheat at three moisture levels for two soils.

The percentage protein in grain grown on the loam was significantly increased with the two highest rates of nitrogen, while on the loamy sand there was no significant change in the protein content between the nitrogen treatments. However, there was a significant increase in the total protein of the grain with each increasing increment of nitrogen on both soils. The large yield response to nitrogen on the coarse soil was manifest in the significant increase in the total protein even though there was no significant increase in percentage protein.

The yield response to the moisture x nitrogen interaction for each soil is shown in Figure 1. The yield response to nitrogen on the loam soil was greater with increasing moisture levels, while on the loamy sand soil there was essentially the same response to nitrogen at all three moisture levels. The largest yield increase per unit of nitrogen was on the sandy loam soil. The means for moisture levels showed that, while the yield response per unit of nitrogen was greatest at the lowest rate (30 pounds N per acre) on the loam soil, the highest application (90 pounds N per acre) produced the greatest yield response per unit of nitrogen on the loamy sand soil.

Figure 2 depicts the effect of the moisture x nitrogen interaction on the percentage protein. In the loam soil the percentage protein, unlike the yield response, was decreased with increasing moisture. The highest in-

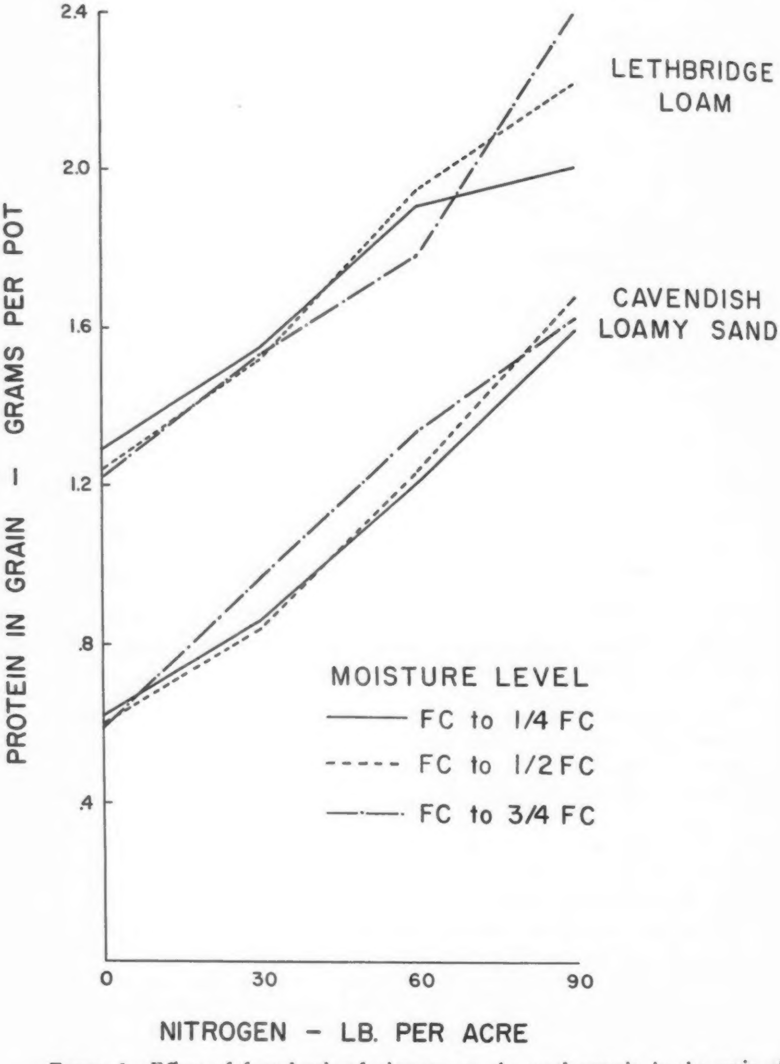

FIGURE 3. Effect of four levels of nitrogen on the total protein in the grain of spring wheat at three moisture levels for two soils.

crease in percentage protein per unit of nitrogen on this soil was at the lowest moisture level and at the highest nitrogen application. Moisture at one-quarter and one-half of the available moisture in the loam soil did not permit complete utilization of the nitrogen applied at the highest rate (90 pounds per acre) in terms of grain yield. However, the nitrogen that

was not used in increasing yield apparently was used by the plant to increase the protein content of the grain. Moisture and nitrogen did not have any significant effect on the protein content of wheat grown on the loamy sand soil.

The weight of protein in the grain as affected by the moisture x nitrogen interaction is shown in Figure 3. In both soils the total protein in the grain was not significantly affected by moisture level but was significantly increased with each increasing level of nitrogen.

The large differences in growth of wheat between soil types most likely were due to the differences in the total nitrogen in the two soils before treatment. An analysis of the unfertilized soils showed that the total nitrogen in the loam was 0.13 per cent compared with 0.05 per cent in the loamy sand. The lower nitrogen content of the loamy sand soil would explain the greater growth response to nitrogen on that soil.

At the rates used, the nitrogen applied to the loamy sand soil was utilized primarily in vegetative growth, and perhaps there was not enough nitrogen left for maximum elaboration of protein in the grain. Because the nitrogen content of the loam soil was originally higher, the nitrogen applied as fertilizer was utilized both in vegetative growth and in protein production in the grain.

Calculation showed that the apparent recovery of nitrogen in the grain per unit of applied nitrogen was 45 and 47 per cent for the loam and the loamy sand soils, respectively.

The results of this investigation indicate the importance of considering soil types in irrigation and fertility studies. They show further that the interaction effect of moisture and nitrogen must be considered since the crop responses to the two main factors do not behave independently.

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THE INFLUENCE OF BASE SATURATION AND FERTILITY TREATMENTS ON YIELD AND CATION COMPOSITION OF CROPS GROWN ON TWO BRITISH COLUMBIA SOILS HIGH IN ORGANIC MATTER

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ABSTRACT

The influence of base saturation and fertility treatments on yield and cation composition of oats grown on two British Columbia soils high in organic matter was studied in the greenhouse. Increased base saturation significantly increased: the yield of oat forage on the Alouette soil (an organic soil), calcium uptake on both soils, magnesium content of oats grown on the Pitt soil, and tissue potassium with the Alouette soil.

The yield decreased significantly when nitrogen was added to the Alouette soil. Nitrogen significantly increased tissue calcium on the Pitt soil. The magnesium and potassium content of oats was not influenced by nitrogen.

With the Pitt soil there was a consistent (but not significant) trend showing that phosphorus increased yields. For the Alouette soil the interaction between phosphorus and base saturation significantly increased calcium absorption. Phosphorus tended to increase calcium uptake from both soils. Tissue magnesium increased significantly when phosphorus was added to the Pitt soil.

There was a tendency (not significant) with both soils for yield to decrease as potassium was applied. When potassium was added to the Pitt soil there was a marked tendency for tissue magnesium to increase. A reverse trend occurred with the Alouette soil. Potassium fertilization of both soils significantly increased potassium absorption.

INTRODUCTION

The two most extensive soil types classified in a recent soil survey of the Pitt Meadows area of British Columbia are the Alouette silt loam and the Pitt silty clay (10). These soils belong to the Dark Grey Gleysolic great soil group and have A_e horizons that are very acidic and high in organic matter. Poor drainage has been considered in the past as the main factor limiting crop production on these soils. A recent improvement program has greatly improved drainage in the area[6]. There will now be an increasing need for accurate information on the lime requirements and fertility status of these soils. A treatment consisting of lime, compost, nitrogen, phosphorus and potassium was reported by Cunningham and Rideout (9) to produce the highest yield of barley on these soils.

The effect of liming and fertilization on the cation composition of crops is of wide interest since forage quality is known (1) to be influenced by cation composition. Recently, significant quantities of Sr^{90} have been

[1]Contribution from the Department of Soil Science, University of British Columbia, Vancouver, B.C. This paper includes portions of a thesis submitted by the second author in partial fulfilment of requirements for the B.S.A. degree at the University of British Columbia.

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[6]*Personal communication*, E. C. Hughes, B.C. Dept. of Agriculture, New Westminster, B.C. 1959.

TABLE 1.—THE BASE SATURATION AND FERTILITY TREATMENTS USED IN THIS STUDY

Soil	Total exchangeable cations equivalents/pot.			Agricultural limestone tons/acre		N	P_2O_5	K_2O
	Base saturation[1,2] per cent			Calculated base saturation[2] per cent			lb./acre	
	Field	30	90	30	90			
Alouette silt loam	0.133	0.297	0.892	2.9	17.0	0	0	0
Pitt silty clay	0.064	0.336	1.007	2.8	12.1	30	60	40
						60	120	80

[1]Field base saturation of the Alouette silt loam and the Pitt silty clay are 13.4 and 5.7 per cent respectively
[2]Although not shown, observed per cent base saturation values were within 10 per cent of the calculated values

found in powdered milk (4, 15) and soil samples taken in the Fraser Valley (2). The radiobiological hazard of Sr^{90} in foodstuffs can be reduced by decreasing the ratio of Sr^{90} to Ca (19). Applications of $CaCO_3$ and $CaSO_4$ have been observed (19) to reduce Sr^{90} uptake from acid soils low in native Ca supply. Any fertility treatment that enhances Ca uptake may thus reduce the potential hazard of this isotope.

Dairying is the main type of agriculture in the Pitt Meadows area and the cultivated acreage is used mainly for hay, pasture, oats and silage corn (10). Oats and red clover were selected for study since they usually appear in the rotations used in this area. The results of the red clover experiment will be reported later.

The objectives of this study were to determine how the yield and cation composition of oats grown on two British Columbia soils high in organic matter were affected by: (a) degree of base saturation; (b) three levels of nitrogen, phosphorus and potassium; and (c) interaction of base saturation with nitrogen, phosphorus and potassium.

MATERIALS AND METHODS

The soils used were the A_c horizons from the Alouette silt loam and the Pitt silty clay*. Following air-drying these soils were passed through a 4-mesh sieve and subsequently used for greenhouse study. Some characteristics of the two soils are listed in Table 2. It should be noted that the A_c horizon of the Alouette is an organic soil while the A_c horizon of the Pitt is not since its organic matter content falls short of the commonly accepted value of 20 per cent.

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*The authors are grateful to W. D. Holland and other members of the Soil Survey Branch, B.C. Department of Agriculture, Kelowna, B.C., for their guidance in the soil sampling.

TABLE 2.—SOME PROPERTIES OF THE A_c HORIZONS OF THE ALOUETTE SILT LOAM AND THE PITT SILTY CLAY

	Exchange capacity me./100 gm.	Exchangeable bases me./100 gm.			Base saturation per cent	pH	Organic matter per cent	Total phosphorus per cent	Total nitrogen per cent	Mechanical analysis[1] per cent		
		Ca	Mg	K						Sand	Silt	Clay
Alouette	75.3	5.0	4.5	0.6	13.4	4.1	67.7	0.06	2.91			
Pitt	49.3	0.8	1.5	0.2	5.7	5.1	18.3	0.12	0.62	7	39	54

[1]The results for the Pitt silty clay A_c horizon taken from report by Holland, W. D., A. L. van Ryswyk and C. C. Kelley. Soil survey of Pitt Meadows municipality. Preliminary Report No. 1, mimeographed. Kelowna, B.C. 1957.

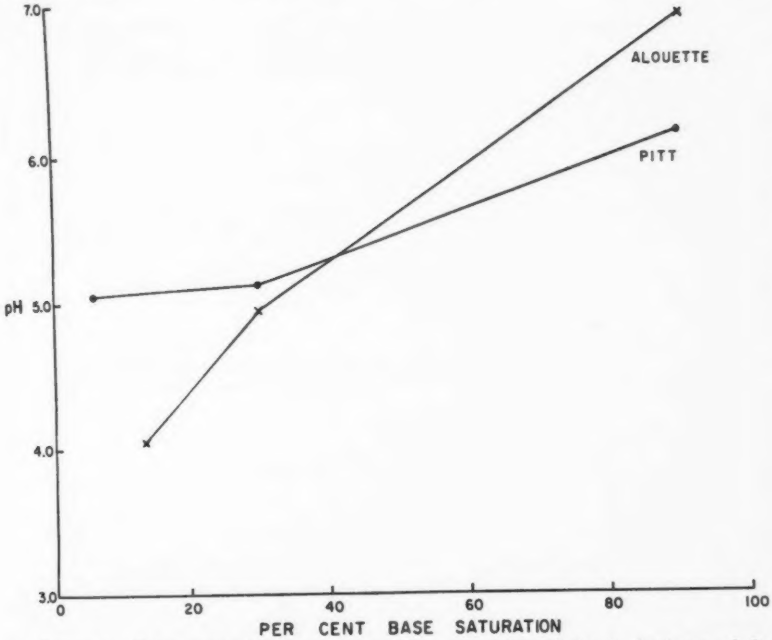

FIGURE 1. Relationship between pH and base saturation of the A_c horizons of the Alouette silt loam and the Pitt silty clay.

Five pounds of the Pitt soil and 2.9 pounds of the Alouette soil were placed in 128-ounce cans. The inner surfaces of these containers were lined with Static Asphalt Protective Coating, Unfibrated Type No. 1. Sufficient calcium carbonate was added to raise the per cent base saturation of the exchange complex from field saturation to 30 and 90 per cent respectively. As required, finely ground agricultural limestone and treble superphosphate were thoroughly mixed with the soils before potting. Potassium and nitrogen were supplied from solutions of ammonium nitrate and potassium chloride. The rates used are shown in Table 1.

A 3^4 factorial design was used with four replicates for the Pitt soil and three replicates for the Alouette soil. In this study the comparisons were restricted to the main effects of base saturation, nitrogen, phosphorus and potassium and to the first order interactions of base saturation with each of these major plant nutrients. The treatments were randomized in complete blocks on the greenhouse bench. At frequent intervals the containers were systematically rearranged within each block.

Soil moisture was kept at or near optimum with surface applications of distilled water. After a period of approximately 1 month oats were seeded. These were later thinned to seven plants per tin. Seventy-four days after seeding the oat plants were harvested by cutting the above-ground portions off, 1 inch above the soil surface. The tissue was then dried at 60°C., weighed, ground in a Wiley Mill and stored for analysis.

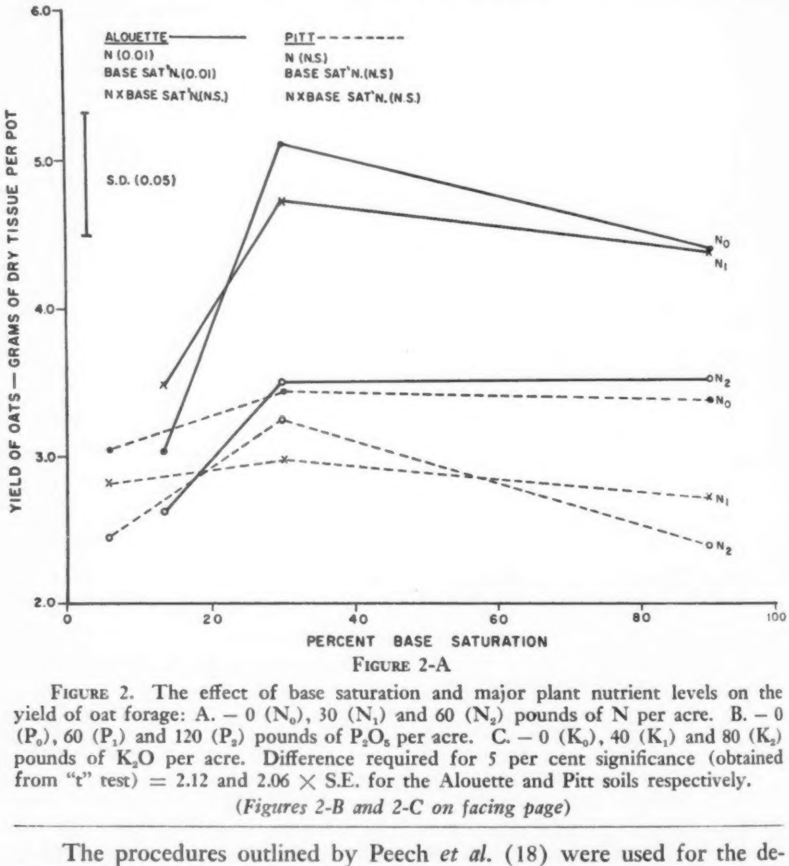

FIGURE 2-A

FIGURE 2. The effect of base saturation and major plant nutrient levels on the yield of oat forage: A. — 0 (N_0), 30 (N_1) and 60 (N_2) pounds of N per acre. B. — 0 (P_0), 60 (P_1) and 120 (P_2) pounds of P_2O_5 per acre. C. — 0 (K_0), 40 (K_1) and 80 (K_2) pounds of K_2O per acre. Difference required for 5 per cent significance (obtained from "t" test) = 2.12 and 2.06 × S.E. for the Alouette and Pitt soils respectively.

(*Figures 2-B and 2-C on facing page*)

The procedures outlined by Peech *et al.* (18) were used for the determination of organic matter, pH, exchange capacity and exchangeable ions. The Bray method (6) was used for the determination of total phosphorus. Total nitrogen was determined as outlined by Jackson (12). Percentages of sand, silt and clay were determined by the Bouyoucos hydrometer method (5). Plant material was dry ashed at 500-550°C. and the ash dissolved in 5 N nitric acid. Flame photometric methods were used to determine calcium and potassium (23). Magnesium was determined according to Cheng and Bray (7).

RESULTS AND DISCUSSION

Figure 1 illustrates the relationship between pH and base saturation of the Alouette and Pitt soils. The Alouette soil showed the greatest increase in pH with an increase in per cent base saturation. The difference in buffering capacity may be partially explained by low exchangeable aluminum (20) present in the highly organic Alouette soil. In addition, basic cations adsorbed by the organic colloids may have relatively greater mobility than those held by clay minerals of the Pitt soil (3).

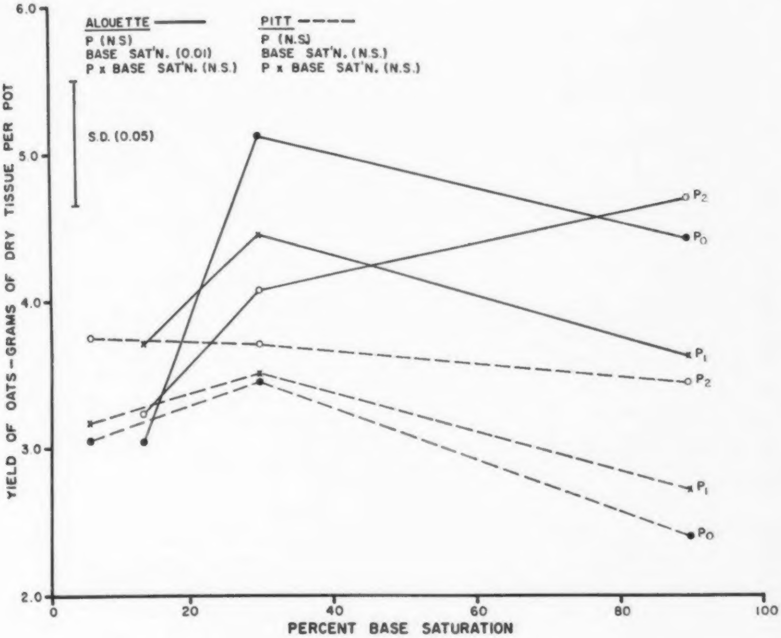

FIGURE 2-B

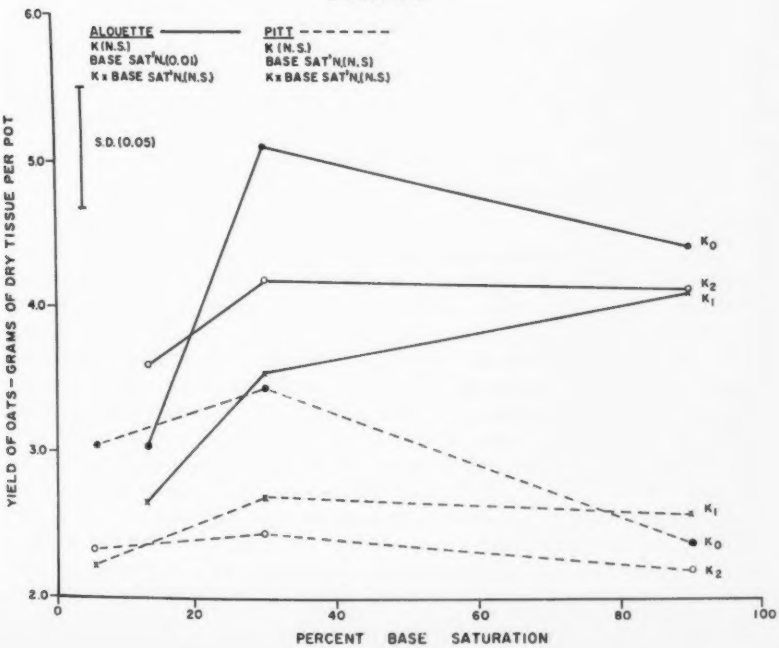

FIGURE 2-C

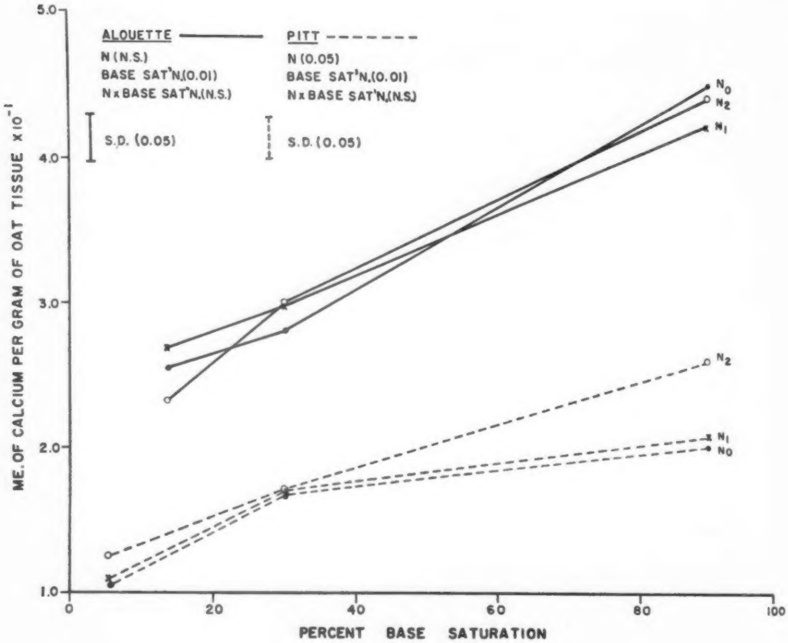

FIGURE 3-A

FIGURE 3. The effect of base saturation and major plant nutrient levels on calcium content of oat tissue: A. — 0 (N_0), 30 (N_1) and 60 (N_2) pounds of N per acre. B. — 0 (P_0), 60 (P_1) and 120 (P_2) pounds of P_2O_5 per acre. C. — 0 (K_0), 40 (K_1) and 80 (K_2) pounds of K_2O per acre. Difference required for 5 per cent significance (obtained from "t" test) = 2.12 and 2.06 $\times$ S.E. for the Alouette and Pitt soils respectively.

(*Figures 3-B and 3-C on facing page*)

Yield

The effect of base saturation and major nutrient level on the yield of oat forage is shown in Figure 2. In Figure 2A it can be seen that, when 60 pounds of N were added to the Alouette soil with a base saturation of 13 per cent (or field saturation) the yield was significantly less than that of the 30-pound application. At 30 and 90 per cent base saturation the forage obtained for 60 pounds of N was significantly less than that of the check and 30-pound treatments. Thirty and ninety per cent base saturation produced significantly more forage than the thirteen per cent level. The main effects of nitrogen and base saturation were not significant on the Pitt soil. It should be noted, however, that at field base saturation there was a consistent trend for yield to decrease as nitrogen was applied. Under the prevailing soil conditions of low pH and low base saturation the nitrogen level of unfertilized soil was apparently optimum for the growth of oats. The Alouette data suggest that when acid soils high in organic matter

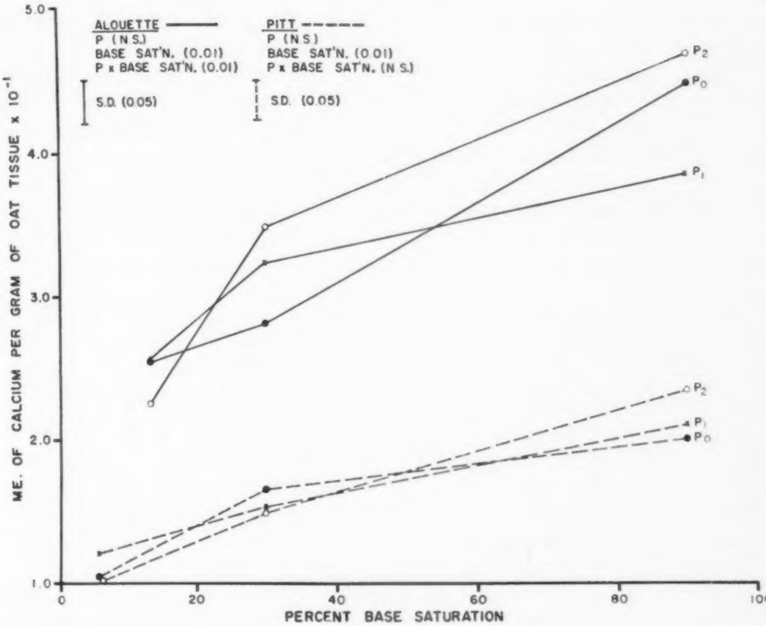

FIGURE 3-B

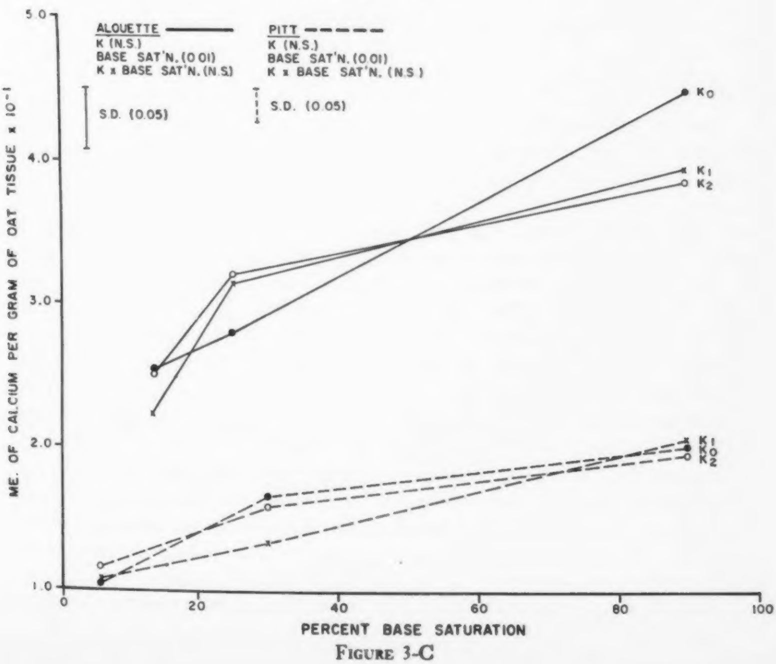

FIGURE 3-C

are limed an increase in nitrate production occurs (16). Here this increase is apparently enough to supply the oat crop needs. The absence of yield response to base saturation with the Pitt soil is not too surprising since other workers (17) have reported that oats are not particularly sensitive to low soil pH. Chu and Turk (8) found that oats did not respond to base saturation above 40 per cent on kaolinitic soils.

With the Alouette soil, phosphorus did not significantly affect oat yields (Figure 2B). Increased base saturation did not produce significant changes with the P_1 rate. When 120 pounds of P_2O_5 per acre (P_2) were applied the yields at 30 and 90 per cent base saturation were significantly greater than that obtained at field saturation. It would seem that liming the Alouette soil to 30 per cent base saturation has increased the availability of native soil phosphorus more than applied phosphorus (13). With the Pitt soil there is a consistent (not significant at $P = 0.05$) trend showing that regardless of base saturation level applied phosphorus increased yields.

For the K_1 application on the Alouette soil the yield of oats was significantly higher at 30 and 90 per cent base saturation than at 13 per cent (Figure 2C). No significant differences occurred with the Pitt soil. There was a tendency (not significant) with both soils for yield to decrease as potassium was applied. This may be the result of reduced phosphate absorption (21).

The yields shown in Figure 2 were always greater for the Alouette soil than for the Pitt soil at base saturation percentages of 30 and 90. At field base saturation the differences were usually not large. These results substantiate the known (20) advantages of liming acid soils high in organic matter.

Calcium

Figure 3(A-C) illustrates the effect of various fertilizer and base saturation treatments on the calcium content of oat tissue. From Figure 3A it can be seen that, regardless of the rate of nitrogen, the calcium content of oats from both soils was significantly greater at 90 than at 30 per cent base saturation. Tissue calcium increased significantly at all levels of nitrogen when base saturation of the Pitt soil was increased from 6 to 30 per cent. With the Alouette soil calcium content increased significantly at the 60-pound rate when the base saturation was increased from field saturation (13 per cent) to 30 per cent. At 90 per cent base saturation of the Pitt soil, a 60-pound N treatment gave significantly more calcium than applications of 0 and 30 pounds of N.

Tissue calcium increased significantly at all rates of phosphorus when base saturation of both soils was raised from field to 30 per cent saturation and when it was increased from 30 to 90 per cent (Figure 3B). Applications of phosphorus did not significantly increase calcium content. There was, however, a tendency for calcium to increase when phosphorus was applied to both soils. The interaction between P and base saturation was significant for the Alouette soil. The addition of phosphorus as superphosphate has been shown (20) to increase the calcium content of grass.

Potassium did not significantly affect the amount of calcium in oats (Figure 3C). Often tissue calcium has been found (20) to decrease when potassium salts are applied. Here the calcium content increased significantly, with both rates of potassium fertilization, when base saturation of the soils was increased.

The increase in calcium content of the oat tissue with increased base saturation is in agreement with the findings of many other investigators (8, 11, 14) who have observed that the per cent calcium in plants increased with higher levels of calcium.

Magnesium

The magnesium content of oats grown on the Alouette soil was not influenced by applications of nitrogen and/or agricultural limestone (Figure 4A). On the other hand, base saturation of the Pitt soil did affect tissue magnesium. The magnesium content of oats treated with 30 pounds of N per acre increased significantly when base saturation was raised from 6 to 30 per cent. Another significant increase occurred when base saturation of the 60 pounds of N treatment was increased from 30 to 90 per cent. It is generally believed that lime applications reduce magnesium uptake (14, 22). Perhaps the added calcium upon being adsorbed by soil colloids (8) has replaced the Mg^{++} ions which in turn appear in bulk soil solution where they may be readily absorbed. In addition, Chu and Turk (8) found that when either Ca^{++} or Mg^{++} ions were complementary to one another on the colloid complex there was a mutual repression of uptake of these ions by rye.

Phosphorus levels had a significant effect on the amount of magnesium present in oats harvested from the Pitt soil (Figure 4B). At field base saturation the magnesium content of oats receiving 60 pounds P_2O_5 per acre was significantly less than those receiving 0 and 120 pounds. The oats treated with 60 and 120 pounds of P_2O_5 at both 30 and 90 per cent base saturation contained significantly more magnesium than those receiving no phosphorus. Tissue magnesium also increased significantly when base saturation of the 60-pound treatment was increased from 6 to 30 per cent. Significant increases were also observed for the 60- and 120-pound rates when base saturation was raised from 30 to 90 per cent. The interaction of P and base saturation was found to be significant for the Pitt soil. Although phosphorus did not significantly affect the magnesium content of oats grown on the Alouette soil, there was a relatively consistent trend for tissue magnesium to increase with rate of phosphate fertilizer. Magnesium is known to aid in phosphate utilization by plants (20, 21) and has been reported (20) to increase phosphate absorption. There are few accounts, however, of magnesium uptake being increased by phosphate fertilization.

Applications of potassium did not significantly alter tissue magnesium on either soil (Figure 4C). There was, however, a marked tendency with the Pitt soil for potassium to increase the magnesium content of oats. On the other hand, a reverse trend occurred with the Alouette soil. Additions of appreciable quantities of potassium, especially to soils low in exchangeable Mg^{++}, have reduced magnesium absorption (20). Base saturation of the Pitt

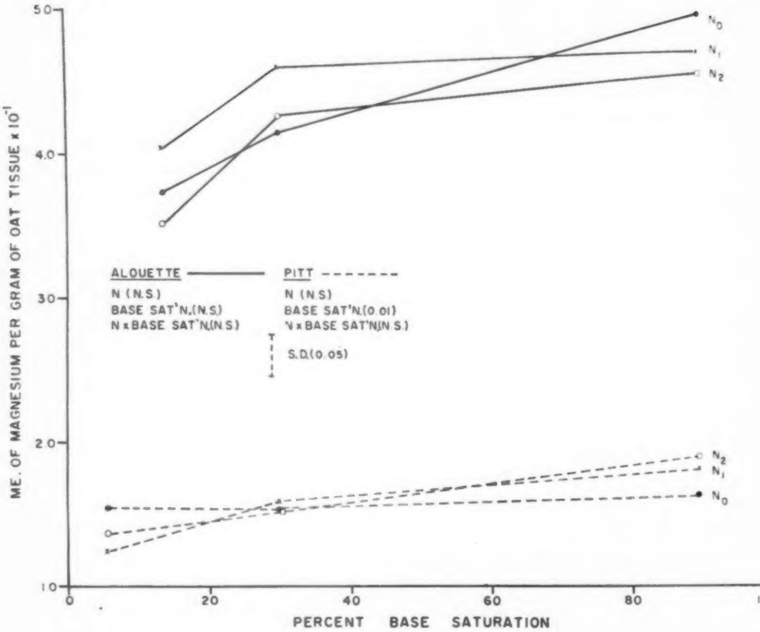

FIGURE 4-A

FIGURE 4. The effect of base saturation and major plant nutrient levels on magnesium content of oat tissue: A. – 0 (N_0), 30 (N_1) and 60 (N_2) pounds of N per acre. B. – 0 (P_0), 60 (P_1) and 120 (P_2) pounds of P_2O_5 per acre. C. – 0 (K_0), 40 (K_1) and 80 (K_2) pounds of K_2O per acre. Difference required for 5 per cent significance (obtained from "t" test) = 2.12 and 2.06 $\times$ S.E. for the Alouette and Pitt soils respectively.

(Figures 4-B and 4-C on facing page)

soil significantly increased tissue Mg. A significant increase occurred when base saturation of the 40- and 80-pound K_2O treatments was increased from 6 to 30 per cent.

Potassium

The addition of nitrogen did not significantly affect tissue potassium (Figure 5A). Oats grown on the Alouette soil treated with 30 pounds of N contained significantly more potassium at 30 and 90 per cent base saturation than at 13 per cent saturation. These results are in agreement with those of Thorpe and Hobbs (22) who reported that potassium uptake by alfalfa was increased by lime applications. On the other hand, it has been shown (14) that absorption of potassium in alfalfa was decreased by liming. York *et al.* (24) found that potassium absorption by alfalfa was not influenced appreciably by other cations.

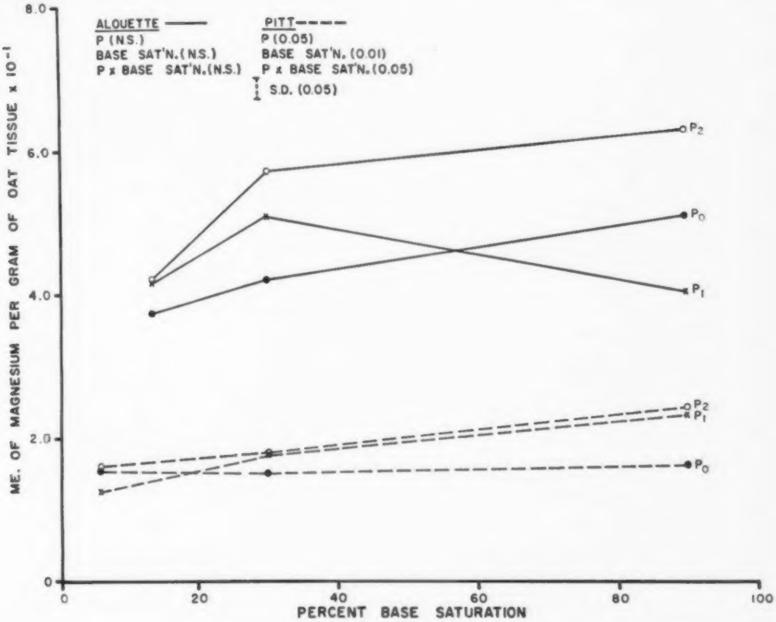

FIGURE 4-B

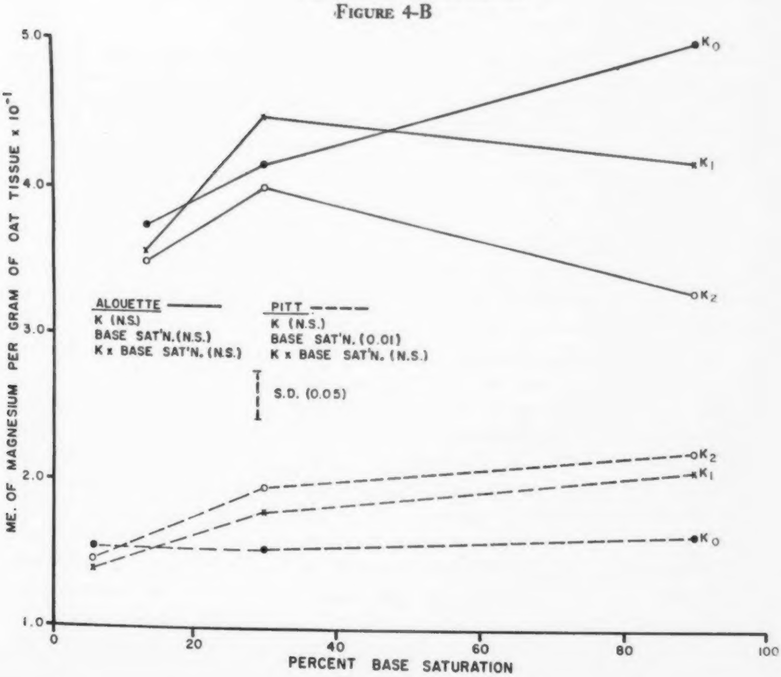

FIGURE 4-C

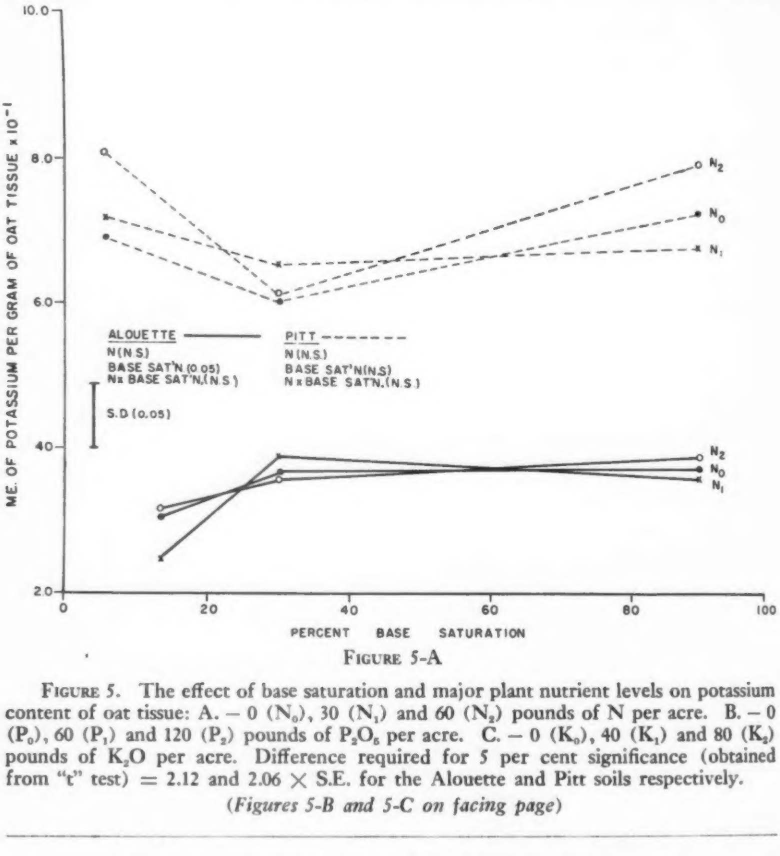

FIGURE 5-A

FIGURE 5. The effect of base saturation and major plant nutrient levels on potassium content of oat tissue: A. – 0 (N_0), 30 (N_1) and 60 (N_2) pounds of N per acre. B. – 0 (P_0), 60 (P_1) and 120 (P_2) pounds of P_2O_5 per acre. C. – 0 (K_0), 40 (K_1) and 80 (K_2) pounds of K_2O per acre. Difference required for 5 per cent significance (obtained from "t" test) = 2.12 and 2.06 × S.E. for the Alouette and Pitt soils respectively.

(Figures 5-B and 5-C on facing page)

It is evident (Figure 5B) that phosphorus did not influence the amount of potassium present in oat tissue. A significant increase did occur, however, when base saturation of the 60-pound P_2O_5 treatment on the Alouette soil was raised from 13 to 30 per cent.

Applications of potassium significantly increased the quantity of potassium present in oats grown on both soils (Figure 5C). In the case of the Pitt soil, treatment with 40 and 80 pounds of K_2O at all levels of base saturation resulted in significantly more tissue potassium than the no potassium treatment. With the Alouette soil at 30 per cent saturation potassium absorption was significantly more when 80 pounds of K_2O were applied than when 40 or 0 pounds were added. At 90 per cent base saturation both 40 and 80 pounds of K_2O produced significant increases in tissue potassium. Here the increase from the 80-pound addition was significantly greater than that obtained with the 40-pound supplement. MacLean (14) observed that potassium fertilization resulted in increased potassium uptake by alfalfa. Base saturation also influenced the amount of potassium present in oats

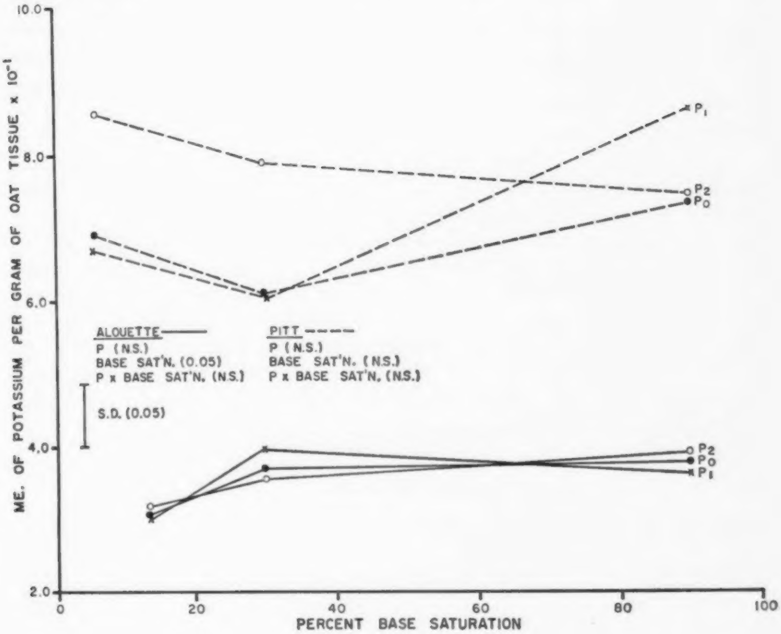

FIGURE 5-B

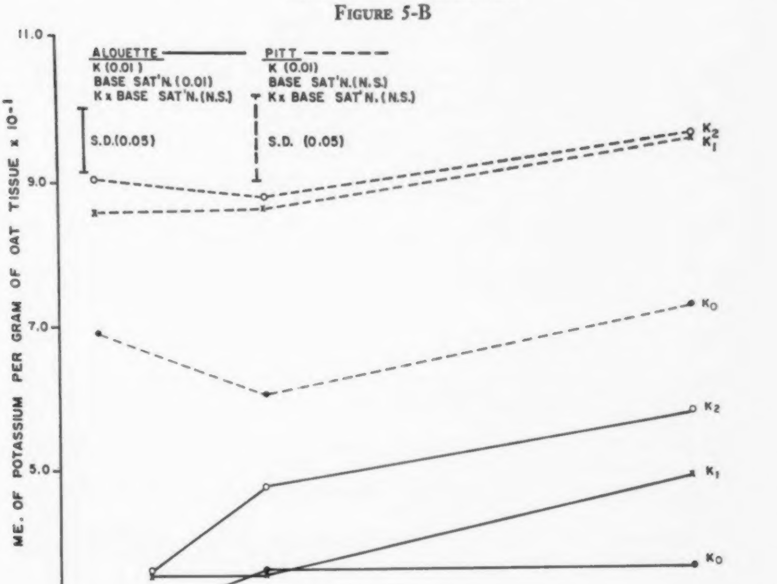

FIGURE 5-C

harvested from the Alouette soil. For the 80-pound rate tissue potassium increased significantly as the base saturation was raised from 13 to 30 and from 30 to 90 per cent. Where 40 pounds of K_2O were added a significant increase occurred only when base saturation was raised from 30 to 90 per cent.

In Figures 3 to 5 it can be seen that, regardless of base saturation and fertilizer treatment, the absorption of calcium and magnesium was greatest from the Alouette soil. Apparently the exchangeable Ca^{++} is released more readily from the Alouette soil (an organic soil) than from the Pitt soil which has the highest total exchangeable Ca^{++} per pot. Magnesium appears to behave similarly; however, the Alouette soil contained slightly more total exchangeable magnesium per pot. With respect to potassium the greatest plant uptake occurred on the Pitt soil. This soil contained less exchangeable potassium per pot than the Alouette soil. The potassium-supplying power (20, 21) of the mineral soil may have been responsible for the greater absorption.

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EFFICIENCY OF PHOSPHATIC FERTILIZERS OF VARYING WATER-SOLUBILITY

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ABSTRACT

Three fertilizers containing various amounts of citrate- and water-soluble phosphates were compared with superphosphate and rock phosphate in field and greenhouse experiments.

Yield curves and equations were calculated and drawn and, from these, availability coefficients were calculated.

The phosphate availability of the fertilizers was reduced as the relative amount of water-soluble phosphate they contained was reduced. However, in fertilizers that contained a relatively large amount of water-soluble phosphorus, the citrate-soluble fraction was partly available.

INTRODUCTION

On alkaline and calcareous soils water-soluble forms of phosphatic fertilizers are generally preferred to the less soluble forms (6, 7, 11). In many cases during fertilizer manufacture, as in the process of superphosphate ammoniation, or in the production of mixed fertilizers, phosphatic compounds only slightly soluble in water are formed.

The evaluation of phosphorus availability in fertilizers on calcareous and other Israel soils seemed to be of considerable interest. There is some evidence in the literature, and it was found in a greenhouse experiment by one of the present authors (5, 8, 9), that the general belief in the superiority of water-soluble compounds over the citrate-soluble ones on calcareous soils is not always fully justified. It was suggested (8) that water-solubility may be a poor criterion for the evaluation of phosphatic fertilizers on these soils.

The purpose of this investigation was to examine, under field and greenhouse conditions, the comparative efficiency of fertilizers varying in the water-solubility of their phosphatic compounds.

MATERIALS AND METHODS

Five fertilizers were compared in a field and greenhouse experiment (Table 1). As may be seen from the description, fertilizers A, B and C are mixed fertilizers, containing phosphorus compounds soluble in water in varying degrees, i.e., mixtures of mono- and di-calcium phosphates. The single superphosphate was included in the experiment as a standard fertilizer. The rock phosphate is a local material and, in spite of its insolubility, it was considered worth while to try its effect, as it could be a cheap source of phosphate and is believed by some farmers to be at least slightly efficient as a source of phosphorus.

Fertilizers A and B contain nitrogen, potassium and phosphate, and C only nitrogen and phosphate. In order to raise the nitrogen and potassium to the same levels in all the field and greenhouse treatments, ammonium sulphate and potassium sulphate were added accordingly. All treatments received 60 kg. N and 60 kg. K_2O per hectare (approximately 53 pounds/acre).

TABLE 1.—DESCRIPTION OF FERTILIZERS USED IN THE EXPERIMENT

Code	Description of fertilizers	Origin	Phosphorus fraction (P_2O_5)			Water-soluble
			Total available[1]	Water-soluble	Citrate-soluble	Total available
			per cent	per cent	per cent	per cent
S	Superphosphate	Fertilizers and Chemicals, Haifa	17	17	—	100.0
A	Kampka 14-14-14	Chemische	14	1.5	12.5	10.7
B	Kampka 10-20-10	Fabrik	20	8.0	12.0	40.0
C	Kamp 12.5-22-0	Kalk	22	13.0	9.0	59.1
D	Rock phosphate −<100-mesh −27.5 per cent P_2O_5	Negev	0.3	—	0.3	—

[1]P_2O_5 soluble in a neutral solution of ammonium citrate. sp.gr. 1.09

The phosphorus was applied at four different levels. The first one did not receive any phosphorus and the other three were given 20, 40 and 60 kg. P_2O_5 per hectare (approximately 17.8, 35.5 and 53.4 pounds/acre), based on the total available phosphorus content of the fertilizers A, B, C and S. Because of the very low solubility of the rock phosphate (fertilizer D) this material was applied at the rate of 60, 120 and 180 kg. total P_2O_5 per hectare (approximately 53.4, 106.8 and 160.2 pounds/acre).

The amounts of fertilizers used in the greenhouse experiment were calculated so as to correspond to those in the field experiment. It was assumed that the field contains 2,500,000 kilograms/hectare of soil in the plough layer. Every greenhouse pot contained 7 kilograms of soil, hence it was considered to be a $\frac{7}{2,500,000}$ part of a hectare and the amounts of fertilizers applied were weighed out accordingly.

In the field experiments the treatments were arranged in a split-plot randomized block design with six replicates. The five fertilizers were placed as plots and the four levels of each fertilizer were arranged as the sub-plots. In the greenhouse experiment the treatments were completely randomized and each had four replicates.

The field experiments were carried out at two sites, Gat and Gvulot. These two soils are representative of large areas of agricultural land in the southern part of the country. They are coarse- to medium-textured. The soils for the greenhouse experiment were collected from the same two sites and a third, finer-textured soil from Gan Shmuel was included for purpose of comparison. This soil represents one of the alluvial soils widely found in the northern parts of the country. Some of the soil characteristics are presented in Table 2.

Barley was sown in the field and greenhouse experiments in winter 1957. In the field the grain was harvested in the late spring of 1958. In the greenhouse the barley was cut at the beginning of ear formation in

TABLE 2.—CHARACTERISTICS OF THE EXPERIMENTAL SOILS, 0-30 CENTIMETRE LAYER

Soil	Organic matter per cent	$CaCO_3$ per cent	pH	Texture	P soluble in $NaHCO_3$ p.p.m.	P soluble in citric acid p.p.m.
Gat	0.8	20.5	7.6	Light clay	1.9	11
Gvulot	0.2	3.7	7.4	Sand	2.6	14
Gan Shmuel	1.7	13.5	7.5	Heavy clay	11.6	92

early spring, 1958. Shortly after the barley was cut, maize was sown in the greenhouse in the same pots and grown during the summer of 1958.

The greenhouse techniques and analytical methods were as described previously (4). The plants were cut at the beginning of the flowering stage.

Some of the yield curves were calculated as described by White *et al.* (15), and others were drawn by free hand (12, 13, 14).

RESULTS

Field Experiments

The dry matter yield of barley grain was determined. Analysis of variance (3, 10) of the results obtained at Gat showed that the differences in yields obtained with the various fertilizers were highly significant (at the 1 per cent level), and also that the differences between levels within one fertilizer were highly significant, with the exception of fertilizer D (rock phosphate), where the differences between levels were not significant. Accordingly, concurrent Mitscherlich curves were calculated for fertilizers A, B, C and superphosphate (15), on the assumption that all four fertilizers were capable of producing the same ultimate yield. The calculated yield curves and equations are presented in Figure 1 where, according to the Mitscherlich equation $\log(A-y)=\log A-c(x+b)$, y represents the yield obtained by the x amount of fertilizer; A is the maximum yield obtainable under the prevailing conditions when x tends to infinity; c determines the slope of the curve – it shows the rate at which it approaches the limiting yield and thus indicates the efficiency of the fertilizer tested; and b represents the amount of available nutrient in the soil in units equivalent to those of the fertilizers. By inspection of the curves and c- values in the equations in Figure 1 and the percentage of water-soluble phosphorus in Table 1, one gets a qualitative impression that the efficiency of the tested fertilizers is correlated with the water-solubility of their phosphate content. However, calculations of the relative availability coefficients, done by comparison of the c- values for the tested fertilizers to a standard one – in our case superphosphate – show that the relative efficiency of fertilizers C and A is higher than could be expected from their water-soluble phosphate content (Table 3, columns 2 and 3). Further calculations were performed

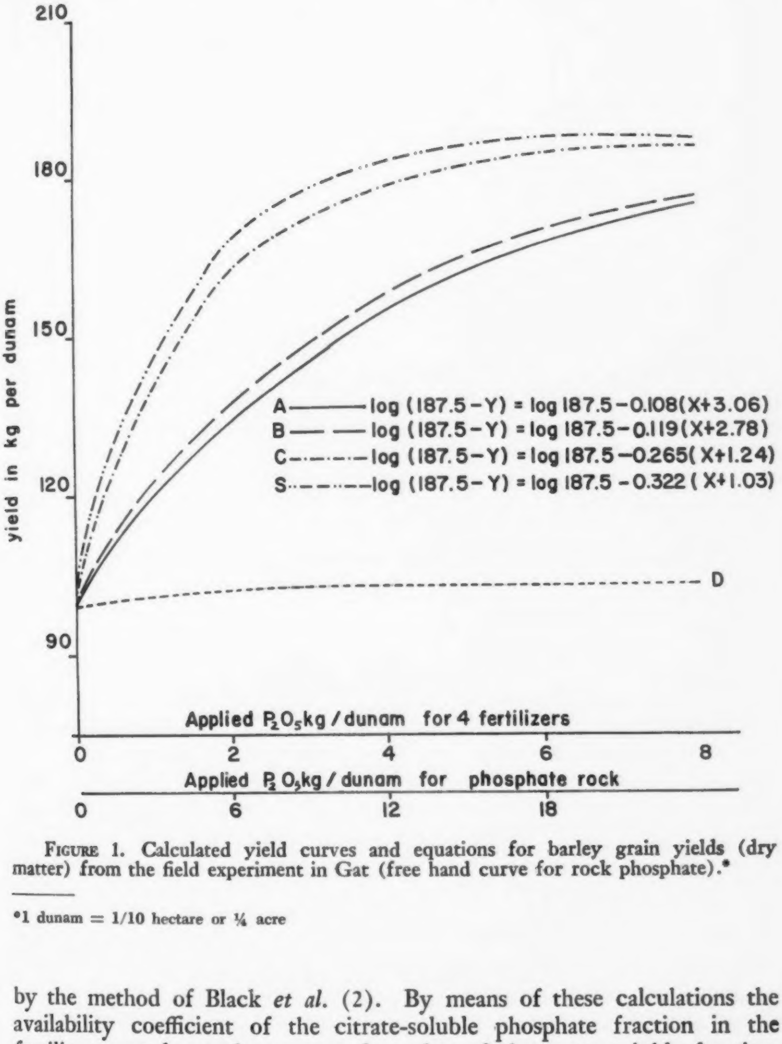

FIGURE 1. Calculated yield curves and equations for barley grain yields (dry matter) from the field experiment in Gat (free hand curve for rock phosphate).*

*1 dunam = 1/10 hectare or ¼ acre

by the method of Black *et al.* (2). By means of these calculations the availability coefficient of the citrate-soluble phosphate fraction in the fertilizers tested may be compared to that of the water-soluble fraction. It is assumed that the water-soluble fraction is of constant availability, regardless of amount and relation to the citrate-soluble one. It was found (Table 3, column 4) that, in the case of fertilizer C (where 60 per cent of the total available phosphorus was water-soluble) part of the citrate-soluble fraction was available, whereas in B and A (containing 40 per cent and 10 per cent, respectively, of their total available phosphorus in water-soluble form) the availability of the citrate-soluble fraction was markedly reduced.

TABLE 3.—CALCULATED RELATIVE AVAILABILITY COEFFICIENTS FROM FIELD AND GREENHOUSE EXPERIMENTS

Fertilizer	Water-soluble	Field experiment		Greenhouse experiments							
	Total available per cent	Yield of barley at Gat		Yield of barley in Gat soil		Yield of barley in Gvulot soil		Yield of corn in Gat soil		Uptake of P by barley in Gat soil	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Super-phosphate	100.0	1.00		1.00		1.00		1.00		1.00	
C	59.1	0.82	0.56	0.61	0.05	0.87	0.68	0.89	0.73	0.83	0.59
B	40.0	0.37	0.05	0.39	0.02	0.52	0.13	0.70	0.50	0.72	0.53
A	10.7	0.33	0.25	0.38	0.30	0.41	0.34	0.62	0.57	0.47	0.40

(1) = Relative availability coefficient (superphosphate as standard)
(2) = Ratio of the availability coefficient of citrate-soluble phosphorus fraction to that of the water-soluble one in the fertilizer tested

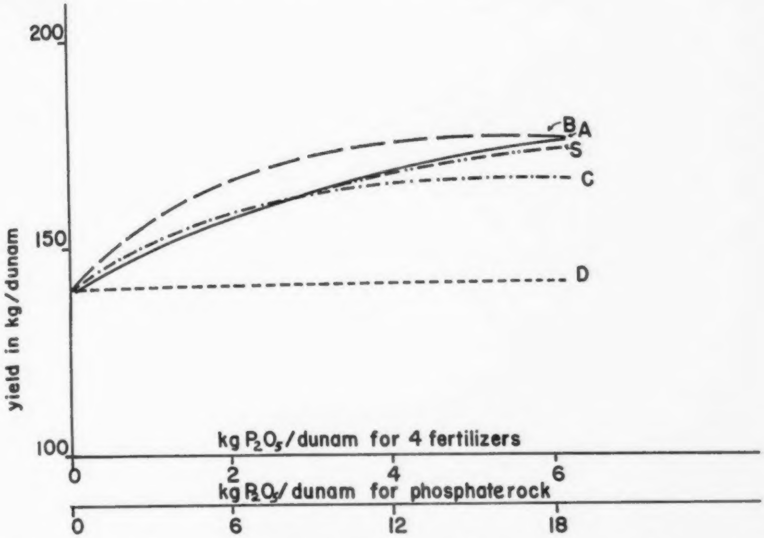

FIGURE 2. Free hand yield curves for barley grain yields (dry matter) in Gvulot.*

*1 dunam = 1/10 hectare or ¼ acre

The results obtained in the field in Gvulot were less satisfactory. Analysis of variance of the yields showed that the differences between the various fertilizers used were significant on a 0.05 level, while the differences between levels within the fertilizers tested were not significant. As these findings did not warrant exact calculations of yield equations and curves, free hand curves connecting the yield data on various fertilizer levels were drawn (Figure 2). Some yield increase may be observed due to phosphorus fertilization in case of the four fertilizers containing citrate- and water-soluble phosphorus. The difference between these fertilizers and rock phosphate is obvious, and the latter did not increase the yield. It should be noted that, in the Gvulot field, the phosphorus fertilizers produced an increase of 30 per cent over the control yield, whereas in the field at Gat the increase was nearly 100 per cent.

Greenhouse Experiments

Concurrently with the field experiments, barley was grown in greenhouse pots. In addition to the soils from the field experiments, a soil (Gan Shmuel) richer in available phosphorus, (Table 2), was tested. Analysis of variance of the yields obtained from the Gat and Gvulot soils showed a highly significant difference between fertilizers and also between levels within each fertilizer, except for differences between levels of rock phosphate which were not significant. Mitscherlich yield curves and equations were calculated for the four fertilizers on the two soils for the barley crop.

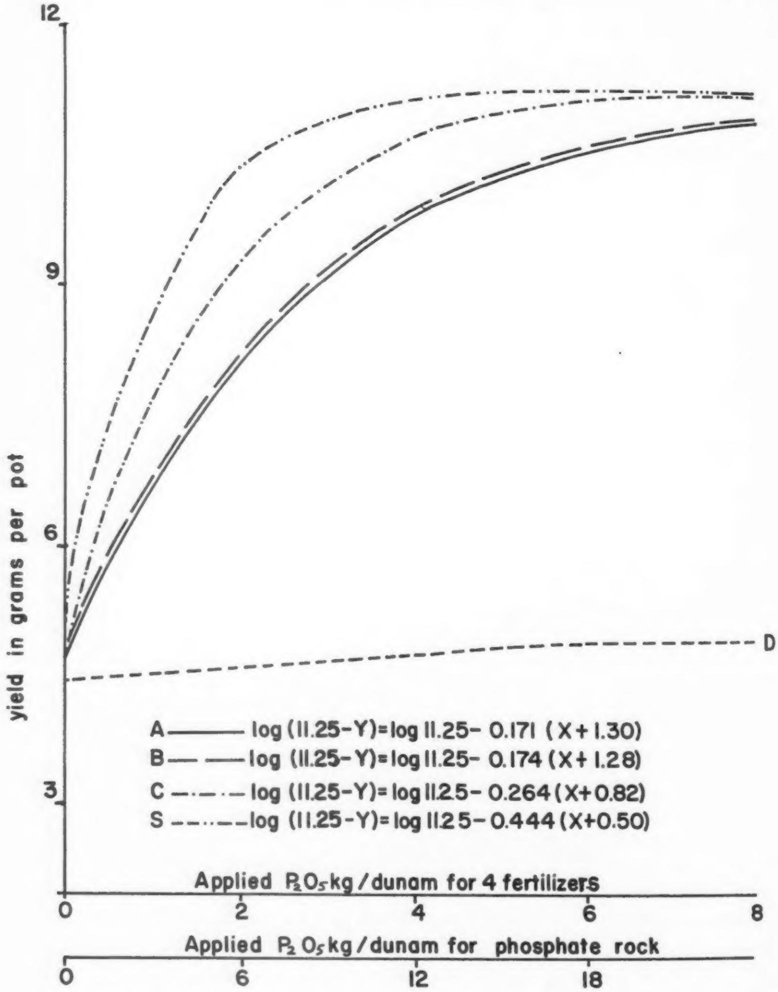

FIGURE 3. Calculated yield curves and equations for dry matter yields of aerial parts of barley plants in greenhouse experiment on Gat soil. (Free hand curve for rock phosphate).*

*1 dunam = 1/10 hectare or ¼ acre

The curves for rock phosphate were drawn by free hand (Figures 3 and 4).

As in the case of the field experiment in Gat, relative availability coefficients for fertilizers A, B and C, when superphosphate was taken as standard, were calculated for the last two experiments (Table 3). The same trend of lower efficiency of fertilizers containing reduced amounts of

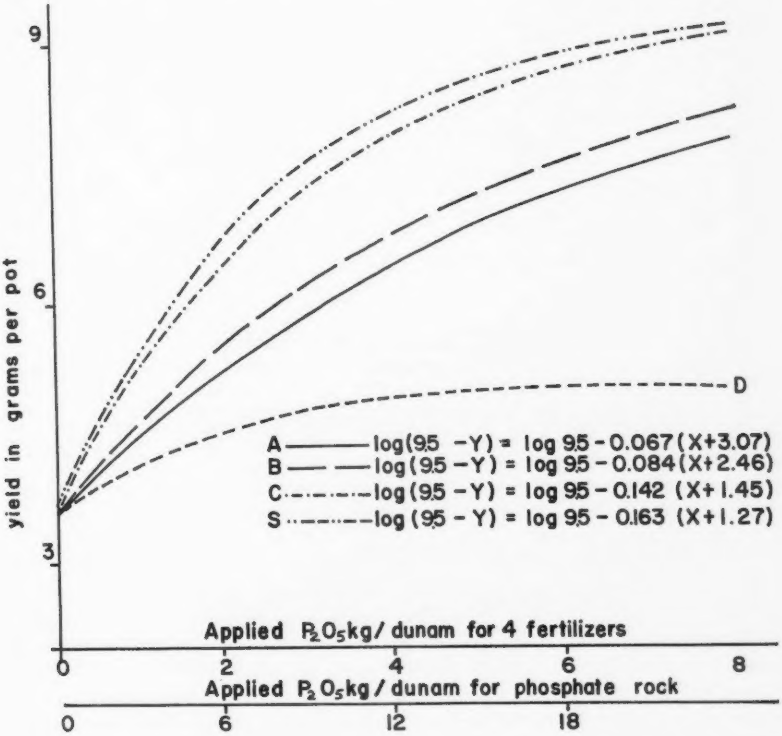

FIGURE 4. Calculated yield curves and equations for dry matter yields of aerial parts of barley plants in greenhouse experiment on Gvulot soil. (Free hand curve for rock phosphate).*

*1 dunam = 1/10 hectare or ¼ acre

water-soluble phosphorus fraction is obvious. In the greenhouse experiment on the soil from Gat the availability of the citrate-soluble phosphorus fraction in the fertilizer C was lower than in the field experiment. The calculated availability of the citrate-soluble fraction in the soil from Gvulot used in the greenhouse experiment with barley was similar to that found for the fertilizers tested in the field experiment at Gat.

Analysis of variance of the yield results for the Gan Shmuel soil showed a significant difference between fertilizers, but the difference between fertilizer levels was not significant. Accordingly, yield curves could not be calculated. In order to present the general trend of the results, free hand yield curves were drawn (Figure 5). It may be seen that additions of fertilizers containing the more soluble forms of phosphorus produced some yield increase, but the less soluble forms were inefficient.

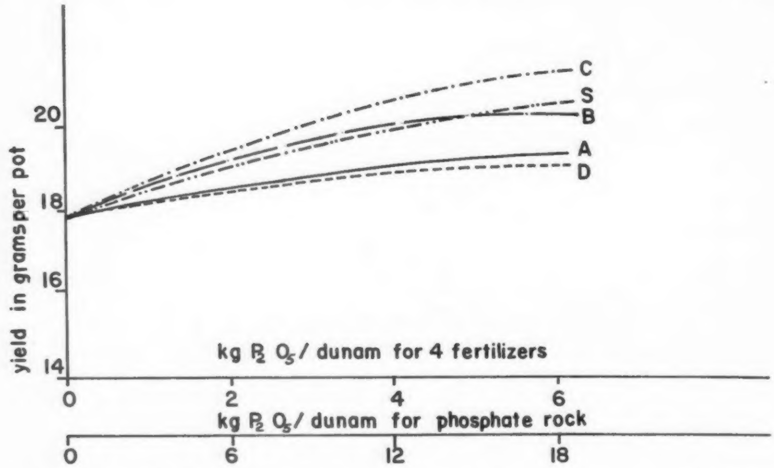

FIGURE 5. Free hand yield curves for dry matter yields of aerial parts of barley plants in greenhouse experiment on Gan Shmuel soil.*

*1 dunam = 1/10 hectare or ¼ acre

Corn was grown in the greenhouse as a second crop on the same soil. Nitrogen was added uniformly to all treatments. Dry matter yield of the aerial parts of the plants was determined. In the Gat soil the differences between fertilizers and between levels within fertilizers were highly significant and yield curves and equations, as well as relative availability coefficients were calculated (Figure 6 and Table 3). The same trend as in the previous experiments was observed. Fertilizers with a higher water-soluble phosphate fraction were again more efficient. However, in this experiment, the relative efficiency of the citrate-soluble phosphate fraction was higher than in the others (Table 3). This indicates a higher residual value for the citrate-soluble phosphate fraction.

The corn crop on the soil from Gvulot partly failed and no results are reported.

The significance of differences between fertilizer levels on the soil from Gan Shmuel was the same for the corn crop as for the previous crop. Free hand curves were drawn (Figure 7) which show a small yield increase due to the more soluble fertilizers, but no increase for the fertilizers containing the less soluble phosphorus.

Total phosphorus uptake in the aerial parts of the barley crop was determined on composite samples representing the four replicates of the different treatments.

On the soil from Gan Shmuel the uptake of phosphorus from the control treatment and from the rock phosphate fertilized soils was similar. With all other treatments it was higher. However, no differences were

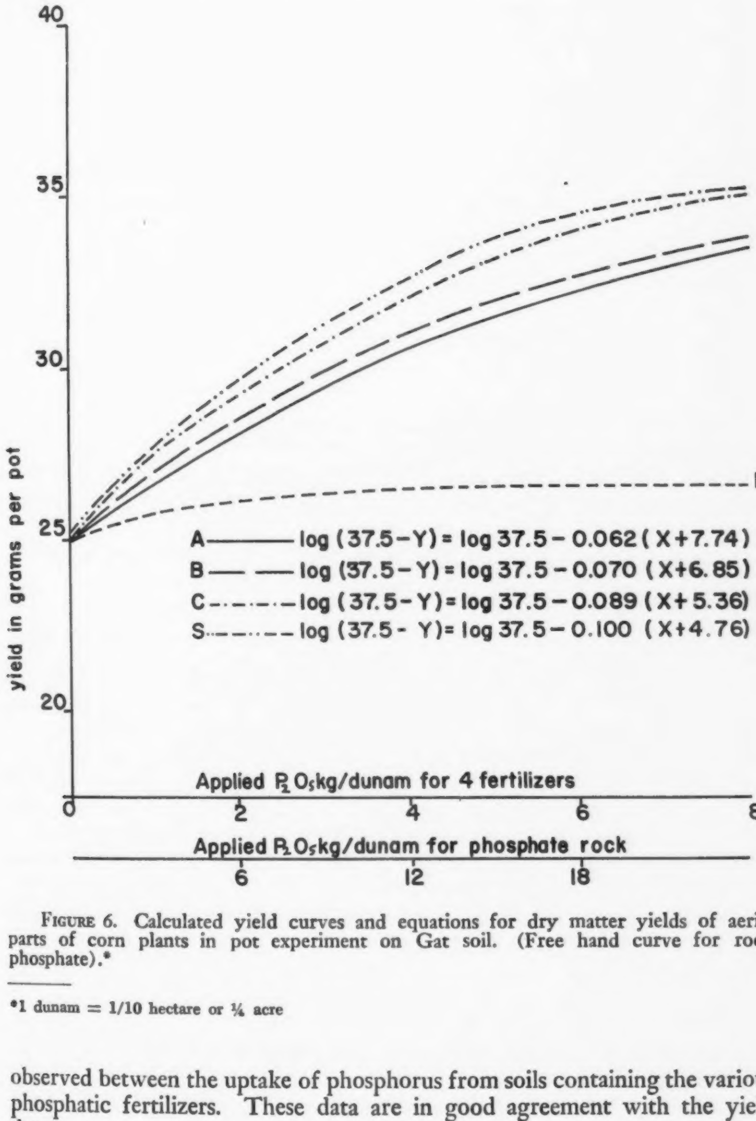

FIGURE 6. Calculated yield curves and equations for dry matter yields of aerial parts of corn plants in pot experiment on Gat soil. (Free hand curve for rock phosphate).*

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*1 dunam = 1/10 hectare or ¼ acre

observed between the uptake of phosphorus from soils containing the various phosphatic fertilizers. These data are in good agreement with the yield data.

The phosphorus analysis data from barley plants growing in the greenhouse on Gat soil showed large differences in the uptake of phosphorus from the various treatments (approximately 3 milligrams per pot in the control to 11 milligrams in the highest level of superphosphate).

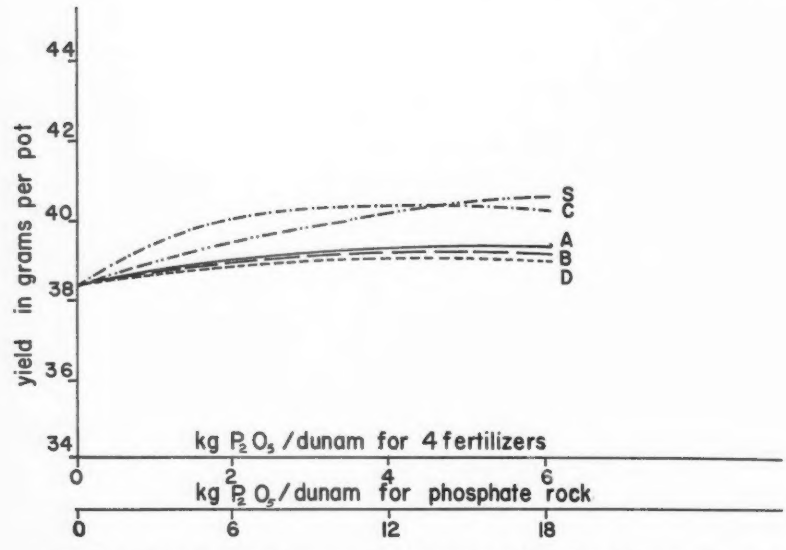

FIGURE 7. Free hand yield curves for dry matter yields of aerial parts of corn in pot experiment on Gan Shmuel soil.*

*1 dunam = 1/10 hectare or ¼ acre

The linearity of the relation between added and absorbed phosphorus was tested for each fertilizer and in most cases the linear regression was found to be significant at 0.01 level. Relative availability coefficients for concurrent straight lines (15) were calculated. In this case, the slopes of the straight lines for the fertilizers tested, compared to the slope obtained for phosphorus uptake from the superphosphate fertilized soil, represent the relative availability coefficients. Judging by the uptake of phosphorus by barley plants, the availability of phosphorus from the fertilizers tested seems higher than by the yields obtained (Table 3, columns 5 and 11).

The relative availability of the citrate-soluble phosphate fraction included in the fertilizers was also calculated. According to these calculations the availability of the citrate-soluble fraction was very similar to that found in the field experiment (Table 3, columns 4 and 12) for fertilizer C. For fertilizers B and A, its availability was approximately 40 per cent to 50 per cent of that of the water-soluble fraction, namely higher than that found in the field experiment.

DISCUSSION AND CONCLUSIONS

The aim of the experiment was to evaluate the relative efficiency of different phosphatic fertilizers containing, in addition to water-soluble phosphates, some amounts of citrate-soluble compounds. Finely ground rock phosphate was also included as one of the experimental treatments.

The field results obtained with the latter material showed that its phosphorus was almost completely unavailable to plants under these experimental conditions, namely in calcareous, slightly alkaline soils.

In general, the field and greenhouse experiments showed that the efficiency of fertilizers was reduced proportionally to the reduction in the relative water-soluble phosphorus content. However, in most cases the citrate-soluble phosphorus fraction was more available when its relative content was lower, than when most of the phosphate was in this form.

The relative availability coefficient of the citrate-soluble fraction compared to that of the water-soluble one in fertilizer C (containing about 60 per cent of its available phosphorus in a water-soluble form) was found, with one exception, to be approximately 0.6 to 0.7. In all experiments, except one, this coefficient was found to be lower for fertilizers A and B than of C, containing about 10 per cent and 40 per cent, respectively, of their available phosphorus soluble in water.

These results may be compared with those obtained by Black *et al.* (2) who state: "the ratio of the availability coefficient of the citrate-soluble phosphorus to that of the water-soluble phosphorus decreased from 0.85 to 0.16 as the fraction of the fertilizer phosphorus in the citrate-soluble form increased from 0.56 to 0.95".

The results of the experiments indicate that the inclusion of citrate-soluble phosphate in fertilizers lowers the availability of their phosphorus. However, when the relative amount of citrate-soluble phosphate to water-soluble phosphate was 40:60, a part of the citrate-soluble phosphate was available in the soils tested. It is probable that smaller relative amounts of the citrate-soluble phosphate would be even more available than was found in this experiment.

It should be noted that, in the calcareous soils tested, citrate-soluble phosphate was available to plants, even if relatively less so than the water-soluble form.

The practical conclusion from the results of the experiment is that inclusion of small amounts of citrate-soluble phosphorus in the process of fertilizer manufacture may not appreciably reduce its availability, and that under certain economic conditions such a process may be advantageous. However, the number of experimental locations in this experiment was too small to draw final conclusions.

ACKNOWLEDGEMENTS

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CHISEL ATTACHMENTS FOR THE BLADE CULTIVATOR[1]

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ABSTRACT

Chisel attachments for the Noble blade cultivator are described. The attachments on the blade holder are designed to chisel a hardpan subsoil to a fixed depth below the blade cut. They differ from the present commercial types of chiseling equipment in that the shanks are attached to a main sub-frame instead of a top-frame. Thus, chiseling with the blade results in a minimum disturbance of the surface mulch and the mulch moving over the blade covers the subsurface vertical grooves or kerfs made by the chisels. Water infiltration is promoted in the surface soil by the surface mulch and in the subsoil by the kerfs. Cultivation with the chisel attachments on the blade does not interfere with the trash mulch necessary for surface erosion control and improves the physical condition of the subsoil.

INTRODUCTION

The crop-residue mulch practice has proven to be one of the most effective means for erosion control in the wheat-growing areas of Canada and the United States (2, 12). This practice appears to have arisen as a response by farmers to dry-land conditions where evaporation of moisture from the soil and wind erosion present serious problems (5, 13). C. S. Noble, of Nobleford, Alberta, was one of the pioneers who contributed greatly to the development of this practice (4). He built the Noble blade in the early 1930's to control soil drifting on his farm (13). Since that time the wide subsurface V-sweep or Noble blade cultivator has received widespread acceptance for the mulch system of farming in many areas of Canada and the United States (3, 16). During subsurface tillage, the horizontal blade undercuts a layer of soil and this layer moves over the sloped blade on each side of the main standard with a minimum of disturbance. Most of the residue is left on the surface and there is practically no ridging (5). The desirable depth of tillage with the blade cultivator is from 2 to 4 inches. The addition of weights makes it possible to maintain a shallow and uniform depth of penetration (6).

In many portions of Western Canada and the United States the soils have a genetic or an induced hardpan in the subsoil. Generally, this layer has low to very low permeability (1) due to its unfavourable structure (8). Subsoiling or chiseling (1) has been advocated to break up this layer in order to improve the physical condition and increase water infiltration (15). In some areas chiseling has proven beneficial (14) but its effectiveness and permanency depends, in a large part, upon the moisture condition of the soil. In order to obtain maximum shattering by this practice the subsoil should be relatively dry (11, 14). The commercial types of chiseling equipment as, for example, the heavy-duty and heavy-duty deep cultivators, have a variety of shank and point designs. However, each chisel is attached on a separate shank secured to a main top-frame. Consequently, during chiseling, each shank disturbs the surface soil, which, under certain conditions, may result in an exposed vertical groove or kerf (7). This practice may leave the soil

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in a vulnerable condition for erosion and for moisture loss by evaporation. Chiseling of the subsoil with the minimum disturbance of the surface mulch would be desirable for improving the physical condition of the subsoil and for erosion control. The chisel attachments, to be described, should accomplish the objective with reference to the cultivation of hardpan soils.

DESCRIPTION OF THE SUBSURFACE CHISEL ATTACHMENT

chisel, and the stationary coulter (Figure 1). The shank is a J-shaped bolt,
The chisel attachment consists of the following parts: the shank, the
the chisel is a curved rod which terminates in a hard-surfaced spike point, and the coulter is a curved steel plate sharpened and hard-surfaced on the concave side. The chisel is welded at a slight angle to the short leg of the shank. The coulter is welded web-like between the chisel and the shank, and thus serves to strengthen the unit as well as to cut the soil and trash under the blade.

The chisels are attached on the blade cultivator by placing each shank in a special groove and hole on the back plate of the blade holder and then tightening a hexagonal nut on the shank (Figure 2). The chisel is held in a vertical position by the chisel-shank offset, symmetrically opposite for each side of the blade, which compensates for the slope of the back plate. During subsurface tillage, the chisels penetrate to a fixed depth of about 4 inches below the cut of the blade. However, the design of the attachment can be altered to permit greater or lesser depth of penetration. The number of attachments regularly spaced on each side of the blade will depend on the soil condition and the power available. Since the chisels are easily attached or removed they can be used only when soil conditions and seasonal practices require or permit such a treatment.

METHODS

Chisel attachments on the blade cultivator were field-tested in order to establish the potential benefits of the attachments. In addition to field observations, an experiment was laid out in 1957 on Solodized Solonetz soils near the irrigation plots* at Youngstown, Alberta. A 5-foot tractor-mounted Noble blade with four chisels attached and the blade with no chisels were used on strips 40 feet by 1,000 feet on each side of a check or a no-cultural strip. The cultural treatments were applied four times during the period June to September, inclusive, at an average blading depth of 3 inches. Supplementary power and additional weights on the blade were provided in order to obtain uniform penetration. The moisture content of the surface (0-6 inches) and subsurface (6-12 inches) soil was obtained at seventeen uniformly-distributed locations in each strip before (June 1957) and after (May 1958) the cultural treatments were applied. In May 1958, penetrometer readings were taken in each strip with a self-recording soil penetrometer (9). Three replicated readings were taken at each location. The penetrometer readings were evaluated by averaging the depth of isoprobe for each location (8). This depth was determined on the penetrometer graph at a point when a manual force of 36 pounds was applied on a 5/16 inch

*Irrigation plots, commenced in 1952 as a co-operative operation between the Canada Department of Agriculture Experimental Farm, the University of Alberta, and the Research Council of Alberta.

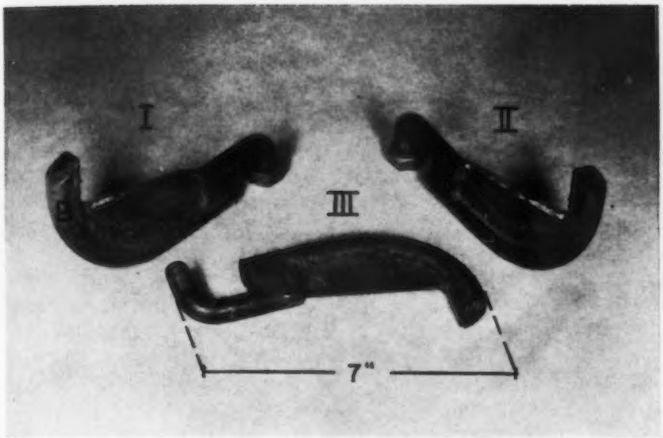

FIGURE 1. Side views (I, II) and top view (III) of the chisel attachments for the Noble blade. The chisel (B) is at a slight angle to the shank (A). The stationary coulter (C) is welded web-like between the shank and the chisel.

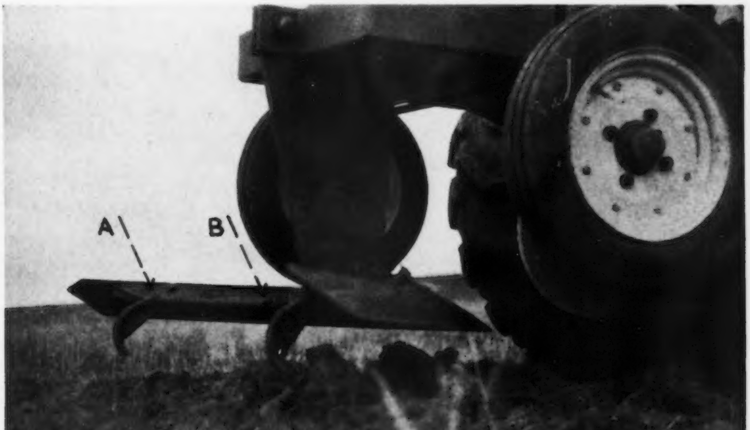

FIGURE 2. The chisels on the blade holder can be regularly spaced (A-B) on each side of the main standard. The mulch flowing over the blade covers the kerfs made by the chisels.

diameter probe. In June 1958, a Tinius Olsen dynamometer was used to determine the draft of the blade cultivator with and without chisel attachments.

RESULTS AND DISCUSSION

Field observations show that the surface mulch flows over the blade and covers the vertical grooves or kerfs made by the chisels, since the chisels are attached to the main sub-frame and are positioned on each side of the standard. The chisels appear to stabilize the horizontal movement of the blade in the soil. In small areas of extremely indurated soil it was necessary to add more weight to the blade to prevent the chisels from lifting the blade out of the soil. There, additional weights were necessary even when blading without the chisels. The chisels appeared to increase the suction of the blade, especially when the subsoil was hard. This increased suction was desirable in the hardpan soil. Under normal conditions there was no accumulation of trash by the chisels, and the stationary coulter kept the chisel free from dirt or trash. However, there was an accumulation of trash by the blade and chisels in extremely hard soil if uniform penetration was not obtained. Ideal conditions for blading with the chisels were evident when it was possible to blade uniformly to a depth of 2-3 inches.

Experimental data show that the use of the blade cultivator on a claypan soil conserved the moisture content of the surface soil. The data in Table 1 show that the surface soil gained 2.9 per cent of moisture when using the blade cultivator while the check strip lost 0.7 per cent of moisture during the same period. However, there was no substantial change in the subsoil moisture when using the blade but the check strip lost 2.0 per cent of moisture. When blading with the chisel attachments the surface soil gained 3.9 per cent of moisture and the sub-surface soil gained 2.6 per cent of moisture. Thus, in this experiment, water infiltration is promoted into the surface and subsoil when using the blade cultivator and the chisel attachments. This cultural method is desirable for erosion control and conservation of soil moisture.

TABLE 1. — EFFECT OF CHISEL ATTACHMENTS ON THE MOISTURE CONTENT OF A CLAYPAN SOIL
(Values expressed as per cent of oven-dry weight)

Treatment	Moisture content (average of 17 samples)				Effect of treatment	
	Prior to treatment		After treatment			
	(June 1957)		(May 1958)			
	0-6"	6-12"	0-6"	6-12"	0-6"	6-12"
Check (no-cultural treatment)	9.1	9.2	8.4	7.2	−0.7	−2.0
Blade cultivator	8.5	10.8	11.4	11.7	+2.9	+0.8
Blade cultivator with attachments	7.0	8.9	10.9	11.5	+3.9	+2.6

TABLE 2. — THE DEPTH OF ISOPROBES IN THE CULTURAL STRIPS

Treatment	Depth of isoprobe (inches) (Average of 51 readings)
Check[1] (no-cultural treatment)	—
Noble blade	14.7
Noble blade with chisel attachments	15.9

[1]Unable to push the penetrometer probe through the surface crust

TABLE 3. — DRAFT OF A BLADE CULTIVATOR WITH AND WITHOUT THE CHISEL ATTACHMENTS IN A CLAYPAN SOIL

Treatment	Depth (inches)	Draft (pounds) (Average of 10 readings)
Blade cultivator	3	1500
Blade cultivator with 2 chisel attachments	3 +4	1700
Blade cultivator with 4 chisel attachments	3 +4	1950
Blade cultivator	5-6	3100

The effect of blading with the chisels on the claypan soil is also evident from the isoprobe data (Table 2). The average depth of isoprobes is greater when the chisels are used on the blade. This greater depth is an indication that the chisels are loosening the subsoil.

There is an increase in draft when using the chisel attachments on the blade. However, the power required when using the blade cultivator with the chisel attachments is less than that required when the blade alone is used at the same depth as the chisels. Dynamometer readings in Table 3 show that blading with the chisels at a total depth of 7 inches requires approximately 1,900 pounds of draft on a claypan soil. Each chisel attachment requires about 100 pounds of draft. Blading at a depth of 5-6 inches with no chisels requires approximately 3,100 pounds of draft. However, power requirements for the blade and chisels will vary according to the depth of the blade and the soil conditions.

Investigation by Naffzigea and Reeves (10) have shown that subsurface tillage with a blade has resulted in a substantial reduction of run-off and soil losses in certain undulating farm lands. Since the chisels promote water infiltration to the subsoil, blading with the chisel attachments on such terrain, and on the contour, would have the additional advantage of reducing subsurface run-off.

The field observations and tests indicate that the chisel attachments on the blade cultivator disturb the claypan layer and promote water infiltration into the subsoil, but maintain the maximum trash cover.

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USE OF A SOIL CONDITIONER TO INCREASE THE PRECISION OF SOIL FERTILITY EXPERIMENTS[1]

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ABSTRACT

Five samples of soil used in a greenhouse study of residual phosphorus were treated with Krilium to eliminate differences in aggregate stability resulting from long-term differential fertilizer treatments.

The improvement in physical condition resulted in increased precision of the residual phosphorus experiment. The increase in precision is attributed to increased yields of ladino clover, increased response of the crop to applied phosphorus, and a reduction in variability.

INTRODUCTION

In soil fertility experiments it is desirable to eliminate all variables except the particular one which is being investigated. In many instances soil physical condition is not a limiting factor and does not contribute significantly to variability. There are cases, however, in which the physical condition as well as the fertility status of the soil is affected by the fertilizer treatments and by cropping systems. This is particularly true of long-term experiments where barnyard manure has been compared with commercial fertilizer as a source of a given element. Where yields are limited by soil aggregate stability and experimental error is increased by variability in this property, it is difficult or impossible to obtain a valid estimate of the fertility status of a soil.

In order to study the effect of variability in soil aggregation on the precision of soil fertility experiments, a greenhouse study was conducted in which a soil conditioner (Krilium) was used to eliminate soil aggregate stability as a variable in a residual phosphorus study.

MATERIALS AND METHODS

Samples of surface soil from a Riverbank sandy loam (3) were selected from the site of a long-term experiment in which potatoes had been grown annually for 24 years. The long-term treatments and their effect on the aggregate stability of the soil are shown in Table 1. Aggregate analysis was done by the Yoder method (4).

Table 1.—Effect of long-term differential fertilizer treatments and of Krilium on degree and uniformity of soil aggregate stability

Soil sample no.	Annual fertilizer treatment (per acre)	Percentage of aggregates >0.25 mm. without Krilium	Rate (%) of Krilium applied	Percentage of aggregates >0.25 mm. where Krilium was applied
1	2000 lb. 4-8-10	23.9	0.23	46.1
2	1000 lb. 4-8-10	22.2	0.16	45.3
3	Check (no fertilizer)	27.4	0.12	46.0
4	16 tons manure	35.3	0.12	48.8
5	8 tons manure+ 1000 lb. 4-8-10	34.1	0.10	45.1

[1]Contribution No. 32, Research Station, Canada Department of Agriculture, Fredericton, N.B.

The rates of Krilium required to bring the soil samples to a given level of aggregate stability were estimated from aggregation curves prepared according to a procedure described in an earlier paper (1). An aggregation status in which 60 per cent of the aggregates in each sample were greater than 0.25 millimetres was chosen as the desired level of aggregate stability. Accordingly Krilium was applied to the samples at the rates shown in Table 1. The data indicate that the predicted level of stability was not attained. The difference between the observed levels and the predicted level may be due to more intimate mixing of the Krilium with the small samples used in preparing aggregation curves. Since the levels obtained represent a marked increase in stability and in uniformity among samples, they were considered satisfactory for the purposes of the experiment. An untreated check was included for each sample.

The soil samples were limed, on the basis of titration curves (2) to pH 6.2. The titration curves were prepared following the conditioner treatment since some soil conditioners have been found to have an effect on soil pH*.

Phosphorus treatments equivalent to 0, and 300 pounds per acre of P_2O_5 were superimposed on the Krilium treatments in a 2 x 2 factorial arrangement. The treatments were replicated four times. A fertilizer treatment equivalent to 40 pounds N, 200 pounds K_2O, 70 pounds MgO and 20 pounds B per acre was applied to all samples. The soil was placed in glazed gallon pots and seeded to ladino clover. The crop was harvested at full bloom.

RESULTS AND DISCUSSION

Emergence of the crop was slow and uneven where no Krilium was applied, particularly on the samples which had not received manure in the long-term fertilizer trial. It should be noted, however, from the response to Krilium shown in Table 2, that soil physical condition must have been a limiting factor even where manure was applied. Where Krilium was applied emergence was rapid and uniform.

*Unpublished data. Can. Dept. Agr. Research Station, Fredericton, N.B.

TABLE 2.—RESPONSE OF LADINO CLOVER TO FERTILIZER PHOSPHORUS AS INFLUENCED BY SOIL CONDITIONER
The data (means of four replications) are yields of clover in grams per pot

Soil sample no.	No Krilium		Krilium	
	No P	P	No P	P
1	6.2	7.1	14.6	14.9
2	4.7	6.4	6.5	12.9
3	0.7	5.4	0.8	15.9
4	8.1	8.2	7.0	16.3
5	6.9	7.7	8.4	15.2
Mean	5.3	6.9	7.5	15.0

TABLE 3.—ANALYSIS OF VARIANCE OF CLOVER YIELDS ON "NO-KRILIUM" AND "KRILIUM" SOIL SAMPLES

Source	D.F.	M.S.		F	
		No Krilium	Krilium	No Krilium	Krilium
Replications	3	7.99	7.17	1.85	1.45
Soil samples	4	31.19	47.33	7.20**	9.60**
Phosphorus	1	26.57	576.84	6.14*	117.00**
Soil samples x phosphorus	4	6.28	56.15	1.45	11.39**
Error	27	4.33	4.93	—	—

Coefficients of variation for no-Krilium and Krilium data were 33.9 and 19.7 per cent respectively

*Significant at 0.05
**Significant at 0.01

Statistical analysis of the data showed that differences in yields due to soil samples, Krilium, and phosphorus are significant at the 1 per cent level. As would be expected from differences in the phosphorus and aggregation status of the samples, the soil x Krilium, soil x phosphorus, and Krilium x phosphorus interactions are also significant. The significance of the soil x Krilium x phosphorus interaction indicates, however, that the soil x phosphorus interaction was not consistent for the two rates of Krilium.

Separate analyses of variance for the Krilium and no-Krilium data (Table 3) show that the soil x phosphorus interaction is not significant where no Krilium was applied; but where Krilium was applied, the interaction is significant at the 1 per cent level. Thus a differential response to phosphorus with respect to soil samples was obtained only where Krilium was applied. The difference in precision is accounted for by the increased yields, the increased response to phosphorus, and the reduction in variability. The coefficient of variation for the no-Krilium treatment was 33.9 per cent as compared with 19.7 for the Krilium data.

It is concluded from this greenhouse experiment that the use of a soil conditioner as a tool in eliminating soil aggregate stability as a limiting factor increases the precision of soil fertility investigations and provides more valid estimates of the fertility status of soils and of their potential productivity.

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THE EFFECT OF FERTILIZERS ON EMERGENCE OF CEREAL GRAINS, FLAX AND RAPE

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ABSTRACT

Ammonium nitrate, ammonium phosphate and treble superphosphate fertilizers placed in a band with seeds of wheat, oats, barley, flax and rape were found to delay and/or reduce emergence. Order of tolerance of these crops was oats > barley > wheat >> rape > flax. The nitrogen fertilizer was more injurious than the two phosphate fertilizers, when applied on the basis of N and P_2O_5 content, respectively. Injury to emergence increased with lower soil temperature. This effect was greatest with treble superphosphate and was only slight with ammonium nitrate. Injury to emergence increased with lower soil moisture content. This effect was very marked with ammonium nitrate but was less with treble superphosphate. For wheat, oats and barley, delay in emergence was more pronounced than reduction. However, for flax and rape relatively light applications of fertilizers both delayed and reduced emergence and exposure of seeds to fertilizer in soils of low moisture content rapidly reduced ability to germinate. Damage to flax was apparently increased by soil micro-organisms.

Injury to emergence was eliminated when fertilizers were broadcast or placed in a band one inch or more away from the seed.

INTRODUCTION

Germination of seeds may be delayed and reduced if placed in contact with commercial fertilizers in the soil (3, 4, 5). Soluble fertilizer salts increase osmotic pressure of the soil solution and may thus retard water uptake by seeds (8). Apart from this effect, certain ions contained in fertilizers are toxic to germinating seeds. Uhvits (8) found germination of alfalfa seeds was reduced by Cl^- uptake. Olson and Dreier (5) reported that at equal rates of N, $CaCN_2$ and NH_4OH were most injurious to germination of wheat, followed by $CO(NH_2)_2 > NaNO_3 > KNO_3 > (NH_4)_2SO_4 > NH_4NO_3$. Guttay (4) suggested that fluorine contained in treble superphosphate was toxic to germinating wheat. Salter (7) stated that order of toxicity of anions commonly found in fertilizers as $NO_3^- > Cl^- > SO_4^{=} > PO_4^{\equiv}$ and mentioned that NH_3 was particularly harmful.

As soil moisture content is decreased, moisture stress is increased, and the effect of salts in delaying and reducing germination becomes greater (2, 5). Damage is more prevalent on lighter textured soils because of their lower water-holding capacity (1). Ammonium phosphate was found more injurious to germination when finely ground than when pelleted (5), presumably because of more rapid solubility. Soil micro-organisms may accentuate injury by growing and attacking seed at osmotic pressures which delay or stop germination (5).

Tolerance of germinating seeds to salt concentration varies amongst species. Ayers and Hayward (1) found barley to germinate at the highest level of salinity for a number of species tested. Guttay (4) reported reduction in germination from fertilizer was less for oats than for wheat.

Fertilizer injury to germination may be avoided entirely if heavy applications are broadcast or placed in the soil away from the seed (4, 6). In

Western Canada fertilizers are usually placed in contact with cereal grains since relatively small amounts are applied per row. Delay and some reduction in emergence from heavy applications of N with the seed have been observed in field experiments in this area. Olson and Dreier (5) reported that ammonium nitrate at 50 pounds N per acre frequently reduced stands and yields of winter wheat in Nebraska and that nitrogen fertilizers were more detrimental than phosphates.

This paper reports the effect of fertilizers on the emergence of wheat, oats, barley, flax and rape. The influence of type and placement of fertilizer and temperature, moisture content and texture of soil are given. These results, obtained under artificial conditions, are compared to the results of field trials.

MATERIALS AND METHODS

Seeds were planted in 2200 grams of soil or sand prepared at various levels of available moisture* and contained in plastic boxes 10 inches long, 5 inches wide and 5 inches deep. In each box 20 seeds were equally spaced in a single row, at a 1-inch depth for wheat, oats and barley, and a half-inch depth for flax and rape. When only one variety of each was used, they were Saunders wheat, Gateway barley, Redwing flax and Arlo rape. Seed samples were of good quality with germination of 95 to 100 per cent and were treated with mercurial seed dressing. Fertilizers used were commercial pelleted forms of ammonium nitrate (33.5-0-0) ammonium phosphate (11-48-0) and treble superphosphate (0-45-0). Fertilizers were placed with seeds to make bands approximately 3/16 inch wide. Rates of application were calculated as pounds of N or P_2O_5 per acre, assuming 7-inch row spacings. When not otherwise specified, ammonium nitrate and treble superphosphate, 1-3 millimetres in size, were used as sources of N and P_2O_5, respectively.

Soils and sand used are described in Table 1. To obtain available moisture contents less than field capacity, water was mixed into the soils or sand. To obtain field capacity moisture content, one layer of soil or sand was placed in the boxes and watered to field capacity from the surface. Seeds and fertilizers were placed on this surface and the remaining sand or soil added and watered to field capacity. In this way the leaching effect of

*Total available soil moisture = field capacity moisture content − wilting coefficient

TABLE 1.—DESCRIPTION OF SOILS AND SAND

Material	Soil series	Texture	Moisture constants (per cent)	
			Wilting coefficient	Field capacity
Soil	Esher-Hythe	Silty clay	14.8	31.6
Soil	Leith	Sandy loam	4.5	18.4
Sand	—	Medium and fine sand	1.3	9.6

water on the fertilizers was minimized. Plastic covers for the boxes reduced losses of added water to less than 5 per cent. After planting, boxes were placed in controlled temperature cabinets or in a room at 55 to 62°F.

Daily counts were made of the number of plants until all emergence had ceased. Time required for emergence was calculated as the number of days until 80 per cent of the final number of plants had emerged. Square root transformations were used to obtain normal distribution of data before statistical analyses. Only those differences found significant are mentioned in the text.

RESULTS

Effect of Fertilizer, Soil Moisture Content and Temperature

Wheat, barley and flax were sown in the silty clay soil at available moisture contents of one-quarter, one-half and field capacity, and temperatures of 45, 55 and 65°F. Ammonium nitrate was applied at rates of 20, 40 and 80 pounds of N per acre and the two phosphate fertilizers at similar rates of P_2O_5. Ammonium nitrate and treble superphosphate were also applied in combination, to obtain 20, 40 and 80 pounds of each of N and P_2O_5.

Treatments were arranged as a 3^2 x 13 factorial.

Emergence of flax was reduced or eliminated by most fertilizer treatments. With one-quarter and one-half available soil moisture at 55 and 65°F., emergence exceeded 50 per cent only with treatments receiving up to 5 pounds N and 20 pounds P_2O_5 and at field capacity only with treatments receiving up to 20 pounds N or 40 of P_2O_5. With one-quarter and one-half available moisture, emergence was lower at 45 than at 55 or 65°F. After emergence had ceased the quarter and half moisture content treatments were brought to field capacity, but no additional plants emerged. Non-germinated seeds were found to be decaying and a mould, *Penicillium spp.*, was prevalent.

Emergence of wheat and barley was delayed by nearly all fertilizer treatments, but on most treatments all plants finally emerged. Final emergence was eliminated or substantially reduced only on those treatments containing 80 pounds of N at quarter and half available moisture. However,

TABLE 2.—EFFECT OF TEMPERATURE, MOISTURE AND FERTILIZERS ON EMERGENCE OF WHEAT AND BARLEY (AVERAGE OF THREE MOISTURE CONTENTS FOR TEMPERATURE COMPARISONS AND VICE VERSA)

	Soil temperature (°F.)			Available soil moisture		
	65	55	45	Field capacity	½	¼
Days for emergence with no fertilizer	6.8	9.5	17.3	9.8	10.7	13.2
Delay (days) in emergence from 40 lb. N per acre	4.8	5.3	5.5	1.7	6.5	7.5
Delay (days) in emergence from 80 lb. P_2O_5 per acre	2.7	4.2	6.7	3.0	4.8	5.7

the majority of the plants emerged when the soil on these treatments was later brought to field capacity. Non-germinated seeds of wheat and barley were decayed and growth of *Penicillium spp.* was apparent.

Since, for wheat and barley, delay was more pronounced than reduction in emergence, the number of days from seeding to emergence was used to measure the effect of fertilizers, crops, moisture levels, temperatures and their interactions. Averaging all soil moisture contents and temperatures, delays in emergence from 20, 40 and 80 pounds of P_2O_5 alone were 0.6, 2.1 and 4.5 days, respectively, and delays from similar rates of N alone were 2.9, 5.2 and 9.7 days, respectively. At equal rates of P_2O_5 the effect of ammonium phosphate was only slightly greater than that of treble superphosphate. However, it was found that pellets of ammonium phosphate were somewhat larger than those of treble superphosphate and, as will be shown later, this could have reduced the effect of ammonium phosphate.

The effects of soil temperature, soil moisture content and two fertilizers on emergence of wheat and barley are given in Table 2. The data in this table are the average of these two crops. While unfertilized wheat emerged 2 days later than unfertilized barley, there was little difference between the two crops in amount of delay caused by fertilizers. The time required for emergence of unfertilized seeds increased with lower soil temperature and with lower soil moisture content.

The delay in emergence from fertilizers increased with lower temperature. This effect was most pronounced with P_2O_5, only slight with N, and intermediate when both N and P_2O_5 were applied.

The delay in emergence from fertilizers increased with lower soil moisture content. This effect was very marked with N, less with P_2O_5, and intermediate when both N and P_2O_5 were applied. This effect is also shown by the data in Table 9. With N fertilizer and fertilizers containing both N and P_2O_5, the effect of soil moisture content was much greater than that of soil temperature.

Comparison of Different Crops

Three varieties of wheat, oats, barley, flax and rape received treatments indicated in Table 3 with soils at half available moisture. Emergence had ceased at 28 days after planting.

TABLE 3.—EFFECT OF FERTILIZER ON EMERGENCE OF FIVE CROPS (AVERAGE OF THE THREE VARIETIES PER CROP)

Soil	Fertilizer (lb. N—P_2O_5 per acre)	Emergence (per cent)					Days from seeding to emergence		
		Wheat	Oats	Barley	Flax	Rape	Wheat	Oats	Barley
Sandy loam	0-0	98	100	98	100	92	9	8	8
	40-40	72	97	93	0	0	20	20	19
Silty clay	0-0	99	98	99	98	90	10	10	8
	40-40	81	97	100	0	0	20	21	17

As shown in Table 3, order of tolerance to 40 pounds N plus 40 of P_2O_5 was oats > barley > wheat >> flax and rape. While emergence of oats was not significantly reduced by the fertilizer, that of barley was reduced on the sandy loam and that of wheat reduced on both soils. Emergence of wheat, oats and barley was delayed from 9 to 12 days by the fertilizers.

Effect of Fertilizers on Emergence of Flax and Rape

Since flax and rape were found more sensitive to fertilizer than the cereal grains, lower rates were used in this experiment (Table 4). Fertilizer pellets 1-2 millimetres in size were used to get more uniform distribution in the seed row. Most emergence took place within 15 days but a few plants emerged as much as 29 days after seeding.

As shown in Tables 4 and 5, emergence was reduced and delayed by all fertilizers. Both reduction and delay in emergence were greater at one-third than one-half available moisture and more pronounced with N than P_2O_5. Reductions in emergence from fertilizers were slightly greater for flax than rape. Considering both delay and reduction in emergence, 10 pounds of N or more than 20 pounds of P_2O_5 per acre, applied in this manner, could seriously reduce stands of flax and rape when soil moisture content is low.

TABLE 4.—EFFECT OF FERTILIZERS ON PER CENT EMERGENCE OF FLAX AND RAPE

Soil texture	Available soil moisture	Rape						Flax			
		lb. N—P_2O_5 per acre						lb. N—P_2O_5			
		0-0	5-0	10-0	20-0	0-10	0-20	0-0	5-0	10-0	0-10
Sandy loam	⅓	100	83	22	0	88	35	100	68	5	80
	½	100	90	40	0	92	55	95	83	35	82
Silty clay	⅓	90	53	23	0	82	50	90	55	13	70
	½	100	87	43	3	100	88	98	80	38	88

TABLE 5.—EFFECT OF FERTILIZERS ON THE NUMBER OF DAYS FROM SEEDING TO EMERGENCE FOR FLAX AND RAPE

Soil texture	Available soil moisture	Rape					Flax		
		lb. N — P_2O_5 per acre					lb. N — P_2O_5 per acre		
		0-0	5-0	10-0	0-10	0-20	0-0	5-0	0-10
Sandy loam	⅓	6	15	23	11	14	8	15	10
	½	6	12	19	9	15	7	13	10
Silty clay	⅓	9	14	27	13	16	11	18	13
	½	6	10	14	8	10	8	13	9

TABLE 6.—PER CENT EMERGENCE OF FLAX WITH VARIOUS FERTILIZER TREATMENTS IN THE FIELD

Location	Days after seeding	lb. N. — P_2O_5 per acre									
		0-0	0-20	0-40	0-80	20-0	40-0	80-0	20-20	40-40	80-80
Blueberry Mountain	29	100	69	62	48	51	23	7	36	15	4
Wanham	11	91	89	64	32	55	29	4	30	13	1
	25	100	98	78	54	67	39	8	44	21	5
Beaverlodge	15	97	—	53	—	—	7	—	—	—	—
	30	100	—	63	—	—	12	—	—	—	—

Flax seeds were very susceptible to decay in the soil but rapeseed was more resistant.

Field Tests

Results obtained using the plastic boxes agreed fairly well with those of previous field tests. In the field tests, treatments shown in Table 6 were applied to wheat and flax at Blueberry Mountain, to flax at Wanham and to wheat, barley and flax at Beaverlodge.

At all three locations, available soil moisture of the seed beds approximated 70 per cent at time of seeding. Rains fell soon after and available moisture varied from field capacity to 50 per cent for 3 weeks after seeding. Moisture content of these seed beds was somewhat above normal and the effect of fertilizers on emergence would be reduced accordingly.

Plant counts showed no significant reduction by fertilizer in the emergence of wheat and barley. Similar results were obtained using soil at field capacity in the plastic boxes. Emergence of flax was reduced by fertilizers at all three locations (Table 6). The first and second counts at Wanham and Beaverlodge show that fertilizers also delayed emergence. The reductions in emergence from N and from the 20- and 40-pound rates of P_2O_5 were of the same order as those obtained in the plastic boxes using soil at field capacity. However, with the 80-pound rate of P_2O_5 reductions were less in the field.

Length of Exposure to Fertilizer

Wheat and flax, fertilized with 80 and 20 pounds N per acre, respectively, were sown in the silty clay soil at one-quarter available moisture and watered to field capacity 0, 2, 4, 6, 9, 12, 15, 18 and 21 days after seeding. With soil watered to field capacity at time of seeding, emergence of wheat was 80 per cent, but on other treatments there was no emergence until the soil was brought to field capacity. Final emergence gradually lessened to 50 per cent with watering at 21 days after seeding.

For flax, watering the soil to field capacity at time of seeding resulted in 75 per cent emergence. With all delayed waterings emergence was almost eliminated. Non-germinated seeds were decayed. Similar results were obtained with both flax and rape fertilized with 20 pounds N or 40 pounds P_2O_5 per acre on the sandy loam soil.

TABLE 7.—PER CENT EMERGENCE OF FLAX ON STERILIZED SAND AND SAND INOCULATED WITH SOIL

Available moisture (per cent)	30		60	
Fertilizer (lb. N — P_2O_5 per acre)	0-0	0-20	0-0	0-20
Sterilized sand	98	43	98	51
Sand plus 3 per cent soil	79	17	90	24

Soil Micro-organisms

It had previously been found that seeds of fertilized flax were quickly decayed in the soil. In an attempt to demonstrate the role of soil micro-organisms, flax was sown in sand sterilized by heat and in sand inoculated with 3 per cent of the silty clay soil. Adding soil to the sand reduced emergence of unfertilized flax slightly and that of fertilized flax by more than one-half (Table 7). While not giving definite proof, this indicates that soil micro-organisms accentuated damage from fertilizer.

Soil Texture

The results presented in Table 3 show the final emergence from wheat and barley fertilized with 40 pounds of N plus 40 of P_2O_5 was greater on the silty clay than sandy loam soil. In the experiment described in Tables 4 and 5, emergence of fertilized rape was greater on the silty clay than sandy loam with one-half available moisture. However, with one-third available moisture and for flax with both moisture contents, differences between soils were not significant. While less damage would be expected with the heavier textured soil, micro-organism activity may have masked the influence of texture on flax and rape which were susceptible to decay in the soil.

Size of Fertilizer

Emergence of both flax and wheat was not influenced by pellet size of ammonium nitrate (Table 8). With treble superphosphate and ammonium phosphate, the 1-2 millimetre pellets were more injurious than 2-3 millimetres. The two phosphates are less soluble than ammonium nitrate and presumably the more rapid solubility of the smaller pellets resulted in more injury.

Width of Fertilizer Band

As is shown in Table 9, reduction in emergence of flax was less with a 1/2- than a 3/16-inch wide band of seed and fertilizer at all moisture contents, but differences were proportionally less at field capacity. Emergence of wheat fertilized with N or P_2O_5 at 80 pounds per acre was slightly more rapid with the wide band but there were no differences in final emergence.

TABLE 8.—PER CENT EMERGENCE WITH TWO SIZES OF FERTILIZER PELLETS IN SILTY CLAY SOIL AT ONE-HALF AVAILABLE MOISTURE

Fertilizer	Ammonium nitrate		Treble superphosphate		Ammonium phosphate	
Pellet size (mm.)	1-2	2-3	1-2	2-3	1-2	2-3
Lb. N — P_2O_5 per acre	10-0		0-30		5-20	
Final emergence of flax (per cent)	43	45	33	47	57	70
Lb. N — P_2O_5 per acre	60-0		0-100		18-80	
Emergence of wheat after 13 days (per cent)	8	8	50	67	53	75

TABLE 9.—EFFECT OF WIDTH OF SEED-FERTILIZER BAND ON PER CENT EMERGENCE OF FLAX IN SILTY CLAY SOIL

Available soil moisture	One-quarter		One-half		Field capacity	
Fertilizer (lb. N — P_2O_5 per acre)	20-0	0-40	20-0	0-40	20-0	0-40
3/16-inch band	0	0	12	32	75	60
½-inch band	0	35	35	75	95	80

Placement of Fertilizer

Wheat and flax were sown in the silty clay soil at available moisture contents of one-quarter, one-half and field capacity and 80 pounds N or P_2O_5 were applied as follows: broadcast; placed with the seed; placed 1 inch below; and placed 1 inch below by 1 inch to the side. When fertilizer was placed with the seed, flax did not emerge and emergence of wheat was delayed and reduced. The other methods of application of fertilizers did not affect emergence of either crop. Similar results were obtained with flax and rape in the sandy loam soil at one-third available moisture.

In the field experiments previously described, fertilizers were also broadcast and placed in bands in the soil at distances of 1 or more inches to the side of or below the seed. While fertilizers placed with the seed reduced and delayed emergence of flax (Table 5), there was no damage from the other methods of application.

DISCUSSION AND CONCLUSIONS

Emergence of the five crops tested was delayed and/or reduced by commercial fertilizers placed in a band with the seed. Order of tolerance of crops was oats > barley > wheat >> rape > flax. Ammonium nitrate was more injurious than the two phosphate fertilizers, when applied on the basis of N and P_2O_5 content, respectively. Results of these tests, conducted under artificial conditions, were substantiated by field trials.

The deleterious effect of fertilizers on emergence increased with lower soil temperature for fertilizers containing P_2O_5, but only slightly for those containing only N. The deleterious effect of fertilizers decreased with lower soil moisture content. This effect was very marked with fertilizers containing N, but less for those containing only P_2O_5. No explanation is offered for the differential response of N and P_2O_5 fertilizers to changes in soil temperature and soil moisture content.

With smaller pellet size of phosphate, damage was increased, presumably because of more rapid solubility.

Results and observations indicated that for flax, which was particularly susceptible to decay, soil micro-organisms substantially increase damage from fertilizers. Olson and Dreier (5) found that soil fungi were more tolerant to high salt concentrations than were germinating seeds and thus contributed to damage from fertilizer.

For wheat, oats and barley in soils at field capacity, there was little reduction in final emergence from fertilizers at the rates used in this study. With soil at one-quarter available moisture content and 80 pounds N per acre, emergence of wheat (the most susceptible of these three crops) was less than 50 per cent, but when the soil was brought to field capacity as much as 3 weeks after seeding, the majority of the plants then emerged. The ability of wheat seeds to germinate was found to be reduced only slowly on exposure to fertilizers in soil at one-quarter available moisture.

Emergence of wheat, oats and barley was substantially delayed by heavy applications of fertilizers. For example, 40 pounds of N plus 40 pounds of P_2O_5 per acre delayed emergence from 9 to 12 days in soil at one-half available moisture content.

Emergence of flax and rape was reduced and delayed by much lower rates of fertilizer. In soil at one-half available moisture, emergence of flax fertilized with 10 pounds of N was less than 50 per cent and was delayed by approximately 1 week. At field capacity, there was emergence with 20 pounds of N or 40 of P_2O_5, but when exposed to these fertilizers in soil at one-quarter available moisture for as little as 2 days, seeds lost their ability to germinate when the soil was moistened.

Under field conditions the seed-fertilizer bands made by some drills would be considerably wider than those used in this study and, as was shown, damage to emergence would be reduced accordingly. Rains shortly after seeding could leach fertilizers, especially nitrogen, away from the seed and thus lessen damage. This study indicates that with the rates of fertilizer currently recommended in Western Canada there would be little reduction in final emergence of cereal grains. However, emergence of cereal grains could be delayed by more than a week when fertilized with 40 to 80 pounds N in a soil of low to medium moisture content, if there was no rain soon after seeding. For rape and flax, nitrogen fertilizers should probably not be placed with the seed since 10 to 20 pounds of N per acre can seriously reduce emergence when soil moisture content is low. With broadcast applications or band placement an inch or more away from the seed, it was found that as much as 80 pounds N per acre did not affect emergence.

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SURFACE TRASH CONSERVATION WITH TILLAGE MACHINES[1]

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ABSTRACT

The conservation or reduction of surface trash resulting from the use of some common tillage implements for cultivating fallow land has been studied in a series of 32 field trials. The weight of the surface trash cover was determined before the first tillage stroke was conducted and again after each operation. The data for each trial were collected over a fallow period of about 2 months and were expressed as a percentage of the original weight of the spring wheat stubble cover.

The wide-blade cultivator reduced the original surface cover by generalized values of 15, 10, and 5 per cent or less after the first, second, and third and subsequent operations, respectively. Results with the rod weeder, when used for secondary tillage, were similar to those given above for the wide-blade cultivator. These machines, if used for two operations on fields initially tilled with the one-way disk, lifted an average of 14 and 11 per cent of the original cover back to the surface.

The heavy-duty cultivator reduced the original surface cover by average values of 30 to 50 per cent during primary tillage and 5 to 20 per cent during the second operation. These results were strongly influenced by factors involved in machine operation.

Generally, the one-way disk and the one-way flexible-disk-harrow (discer) reduced surface cover by 50 per cent during each operation at a depth of 3 to 4 inches. Trash reduction during primary tillage with the one-way disk increased with an increased depth of tillage and decreased with increased weights of surface cover. The tandem disk provided about the same results as the other disk machines.

The use of one or more machines in a tillage sequence provides a means of regulating surface trash on a quantitative basis.

INTRODUCTION

In the open plains area of Western Canada generally, and in the "chinook belt" of Alberta and Saskatchewan in particular, the fall, winter, and spring seasons represent the periods when wind erosion is most likely to occur (10). The quantity of trash left on the soil surface by a sequence of tillage operations involving one or more machines is an important factor in providing protection against soil drifting. The greater the quantity of trash on the soil surface, the greater is the protection provided against the movement of soil by wind. The capacity of a tillage implement to conserve trash is an important characteristic governing the use of the machine for summer-fallowing or for seedbed preparation.

The value of trash cover as a protective agent has been discussed by several authors (7, 8, 10, 11, 13, 14). Ryerson (12) and Woodruff and Chepil (14) have enumerated the features desired in implements required for stubble mulch tillage. Both references stressed the need for implements that maintain surface trash.

Wind erosiveness has been expressed in mathematical terms (1), relating the cloddiness of the soil surface, the quantity of trash, and the average height of the trash to the quantity of soil eroded in a wind-tunnel. Chepil and Woodruff (2, 3) have related, in an exponential equation, the

[1]Contribution from the Soils Section.

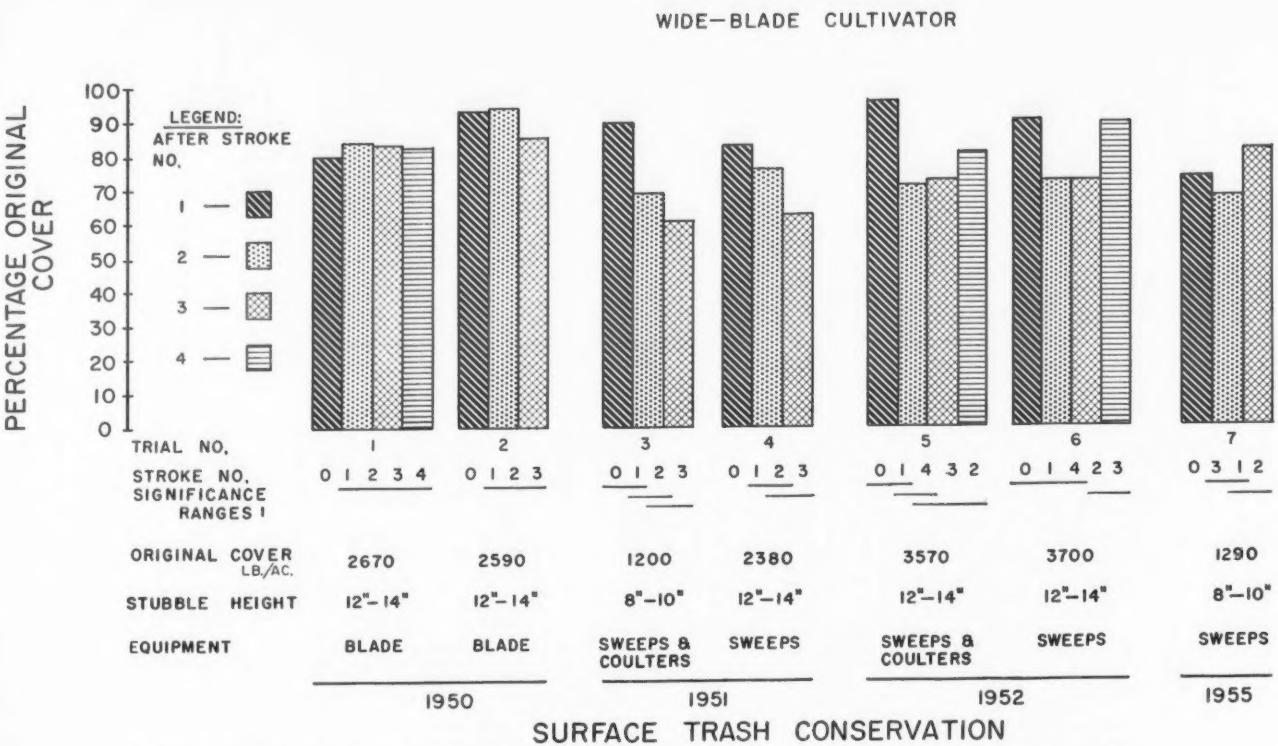

FIGURE 1. Surface trash conserved by the wide-blade cultivator when used for primary and secondary tillage.

[1]The weight of surface trash cover was not significantly different at the 5 per cent level in any comparison involving 0, 1, 2, or more operations if underlined by the same significance range bar.

quantity of residue, the cloddiness of the soil surface, the roughness of the surface, and soil texture to the quantity of soil that can be expected to erode from a field surface under wind action. These relationships emphasize the quantitative aspect of trash cover as a protective medium.

Information has been published indicating the trash conservation characteristics of some tillage tools. Krall *et al.* (8) indicated that each operation of the one-way disk incorporated 30 to 35 per cent of the surface residue and that the blade and weeder sweeps buried 10 to 15 per cent. Woodruff and Chepil (15) reported that about 50 per cent of the surface residues were conserved after the first one-way operation as compared with 85 per cent after the first operation with the blade cultivator. These figures are reasonably similar to those given by Hill (7), who suggested 50 per cent reduction of trash per stroke for the one-way and 10 per cent for the blade cultivator. Siddoway *et al.* (13) found that the subsurface plough left approximately 95 per cent of the surface residue and that the one-way disk left 40 to 60 per cent. They suggested that 60 per cent was left by the one-way disk when the original residues were 4,000 pounds or more. It can be inferred from these data that trash conservation with the one-way disk is related to the quantity of trash handled.

Krall *et al.* (8) used different machines for summer-fallow operations on fields having 4,000 pounds of winter wheat residue. The combination of the one-way disk for the first operation and weeder sweeps on a wide-blade cultivator for subsequent operations reduced the cover by 69.3 per cent as measured in the fall and again at seeding time. The one-way disk followed by the one-way disk-harrow reduced the cover by 97.4 per cent, and the use of chisel points followed by shovels and then the rod weeder reduced the cover by 76.6 per cent.

Woodruff and Chepil (15) studied the effect of angular adjustment, depth of tillage, and speed of operation on trash conservation with the one-way disk. They concluded that: "Shallow depth and small angle one-way tillage accomplished at slow speeds will generally leave more residue than deep depths and wide angles."

McCalla and Duley (9) pointed out that the rate of decomposition of plant residues on the surface was greatly influenced by temperature, moisture, and other factors. They also indicated that, in summer, moisture in surface plant material usually remained favourable for microbial activity for only a short time. In spring and fall, surface residues may remain moist for a much greater length of time. Differences in the length of season over which measurements were taken must be considered when relating the trash conservation data reported by Krall *et al.* (8) to those presented here.

Studies were undertaken at Lethbridge to determine the trash conservation characteristics of several machines when used for cultivating summer-fallow land. The use of one machine for all tillage operations is reported in Part I of "Results and Discussion" and the use of one machine for primary tillage followed by the use of a different machine for subsequent tillage is reported in Part II.

METHODS

The studies were conducted on a Lethbridge silt loam soil in fields about 1 acre in area on which a crop of spring wheat had been grown. The crop was harvested with a direct-cut combine equipped with a straw spreader. Stubble from Marquis spring wheat was used in 1950, 1951, and 1952. Stubble from either Chinook or Rescue spring wheat was used from 1953 to 1958, inclusive. The first tillage operation on the stubble field was carried out during late May, and subsequent work involving one or more operations was completed by about the end of July.

Each field was sampled for surface cover before the first operation was carried out and again after each stroke. Sampling areas were selected in each field for uniformity of height of stubble and straw distribution within each area. Six areas were used in studies conducted in 1951 and earlier, and ten were used in the 1952 and later studies. Duplicate square-yard samples were taken from each area before the first operation was carried out and again after the completion of each stroke. The location of each sampling site within each area was marked to prevent chance re-sampling. Loose straw was lifted, and anchored material was clipped at the surface of the soil. Weedy plant material was discarded from the samples.

The trash samples were brought to an air-dry moisture content of about 12 per cent. Soil was cleaned from the material before the weight was recorded, and the results were expressed as a percentage of the original cover. The data were analysed statistically, using the paired-plot technique (6) to determine, at the 5 per cent level, the significance of the change in surface cover that resulted from the various tillage operations. Significance range bars (5) were used in the charts to show the results of the analysis for each trial.

Machines

The *wide-blade cultivator* used throughout the study was equipped with two standards that supported either a 10-foot straight blade or two 5-foot, 100-degree sweeps. Rolling coulters, 18 inches in diameter, were mounted ahead of the cultivator standards during two of the trials reported here.

The *field cultivator* was equipped with 12-inch sweeps arranged in three gangs for an effective spacing of 9 inches.

The 10-foot *heavy-duty cultivator* was equipped with ¾-inch lift, 16-inch sweeps arranged in three gangs for an effective spacing of 12 inches except for one trial in which 2-inch chisel points and weeder-knife attachments with the points were used.

The 6-foot *one-way disk* was equipped with 24-inch-diameter pans having a concavity of 2½ inches and spaced at 8-inch intervals along the arbor bolt. The angle of cut, as measured between the plane of the cutting edge of the pan and the direction of travel, was maintained at about 40 degrees.

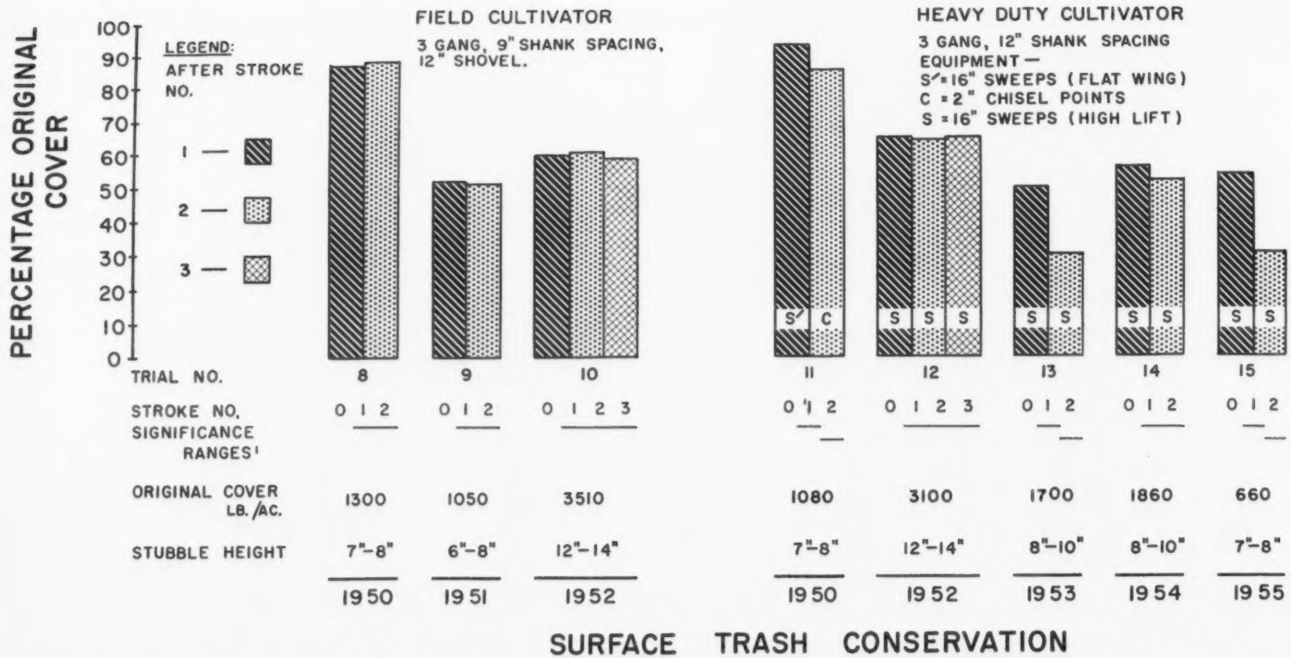

FIGURE 2. Surface trash conserved by the field cultivator and the heavy-duty cultivator when used for primary and for secondary tillage.

[1]The weight of surface trash cover was not significantly different at the 5 per cent level in any comparison involving 0, 1, 2, or more operations if underlined by the same significance range bar.

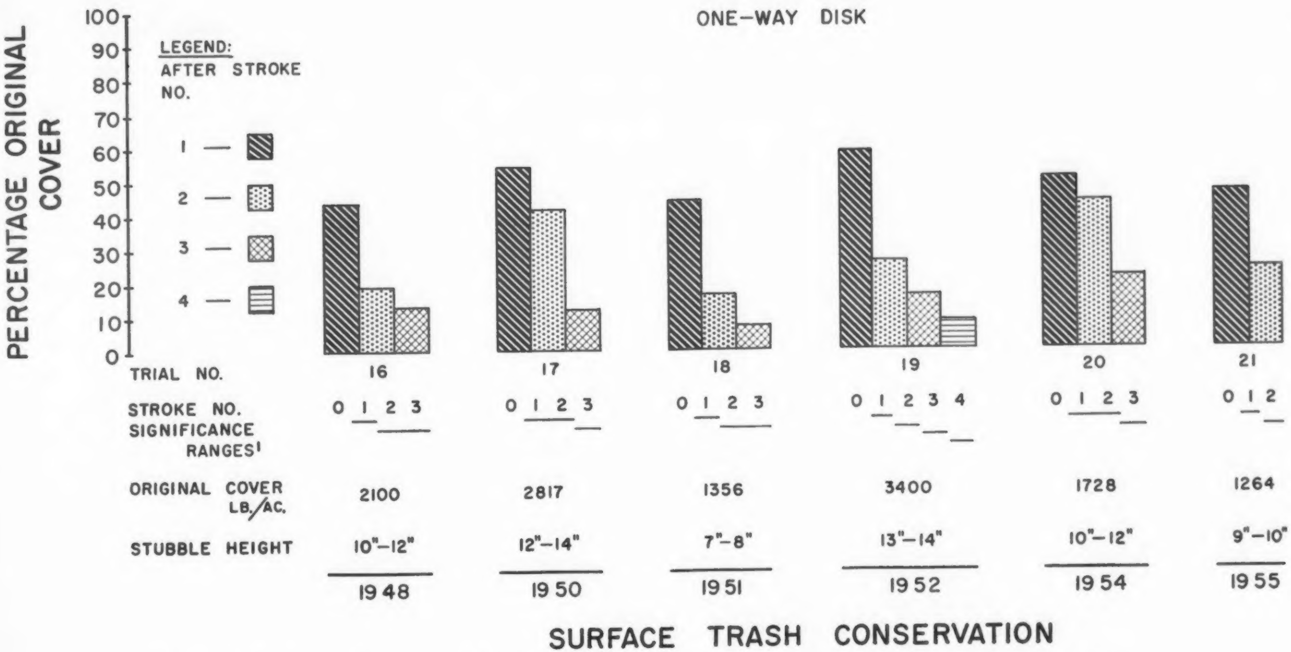

FIGURE 3. Surface trash conserved by the one-way disk when used for primary and for secondary tillage.

[1] The weight of surface trash cover was not significantly different at the 5 per cent level in any comparison involving 0, 1, 2, or more operations if underlined by the same significance range bar.

The 9-foot *one-way flexible-disk-harrow* (discer) was equipped with 18-inch-diameter pans having a concavity of 1⅞ inches and spaced at 7-inch intervals along the arbor bolts of three independent spring-loaded gangs. The disk angle of cut varied between 30 and 35 degrees during these trials.

The *tandem disk* used was a 10-foot unit equipped with 16-inch pans.

The *treader* used was an 8-foot double-gang rotary hoe equipped with 16-inch-diameter, 10-spike wheels spaced 6 inches apart on each gang. The rear gang was offset 3 inches with respect to the front gang. The rotary hoe was pulled behind the wide-blade cultivator so that the spikes provided a treading rather than a weeding action.

Tillage operations were conducted with all machines at a speed of between 3 and 4 miles per hour and at a depth of 3 to 4 inches. Some important variations in speed and depth of operation occurred, and these are noted in the discussion.

RESULTS AND DISCUSSION

Changes in the weight of plant residue material on the soil resulted from three main factors: the action of the tillage implement, natural weathering, and weed growth. Natural weathering is assumed to have had a small influence because most of the trials were conducted over a period of about 2 months. Weed growth was eliminated when the samples were collected.

PART I — ONE MACHINE FOR ALL OPERATIONS

Wide-blade Cultivator

The results obtained from seven studies with the blade cultivator are given in Figure 1.

In trials 1 and 2 primary tillage was conducted in a moist soil in which the straight blade did not scour properly. Significant quantities of trash were buried in the wide kerf marks left by the blade standards. Secondary tillage was conducted in a loose, moderately dry soil, and significant changes in cover did not occur.

The use of wide-sweep equipment with and without rolling coulters was compared over a 2-year period (trials 3 to 6, inclusive). The use of the coulters ahead of the cultivator standards resulted in clean kerf marks, particularly during primary tillage. The coulters cut through loose straw and eliminated bunching. In both the 1951 and the 1952 trials the blade cultivator conserved about 6 per cent more trash during primary tillage with coulter equipment than without. However, the use of coulters did not have a major influence on trash conservation during secondary tillage.

In trials 3 and 4 surface cover was reduced to a greater extent than in other trials reported here. The 1951 season was unusual in that from June 1 to September 1 rain fell on 48 days and totalled 10.96 inches. The mean temperature for this period was 59.7°F. as compared with the 58-year average of 62.4°F. The extended wet weather combined with near-normal temperatures accelerated the rate of decomposition of surface material (9, 16). Soil was quite moist during all operations and the sweeps did not scour properly. Some trash was buried in the kerf marks. This was not

offset by the lifting of buried material to the surface, which was observed when the sweeps were operated in loose and fairly dry soils.

The blade cultivator significantly reduced surface cover when used in a moist soil for primary tillage (trials 1, 2, 4, and 7) and secondary tillage (trials 5 and 6). Secondary tillage conducted on loose, fairly dry soils required the cumulative effect of at least two operations to reduce surface cover significantly. Continuous use of wide sweeps under these soil conditions lifted some buried material to the surface (trials 5, 6, and 7). This material consisted of straw buried in the kerf marks and of root stubs.

Field Cultivator and Heavy-duty Cultivator

The data from three trials with the *field cultivator* are presented in Figure 2. Primary tillage reduced surface cover by about 15 per cent in trial 8 and by 50 and 40 per cent in trials 9 and 10, respectively. The severe reduction was associated with failure of the shovels to scour properly in moist soil. Secondary tillage did not produce a marked change in surface cover. Scouring difficulties were not encountered during second-stroke work. It was observed that secondary operations covered some surface material and that some of the stubble buried by the first operation was returned to the surface by the second stroke.

The trash conservation patterns for the *heavy-duty cultivator* (trials 11 to 15, inclusive) varied considerably. In trial 11 weeder-knife attachments, operated at a depth of about 4½ inches, conserved 90 per cent of the original cover during primary tillage. Secondary tillage with the chisel points reduced the cover slightly. In trials 12 to 15, inclusive, the sweeps were operated about 3½ inches deep during primary tillage. The sweeps produced considerable soil turbulence, and large quantities of loose straw and stubble were buried. In trials 12 and 14 secondary tillage was conducted in a fairly dry soil. It was noted that some of the straw and stubble buried during the first stroke was lifted to the surface. However, secondary tillage did not change the weight of the surface cover in trials 12 and 14. Secondary tillage reduced surface cover in trials 13 and 15. In trial 13 the sweeps were operated with excessive pitch caused by improper hitch adjustment. In trial 15 the combination of poor scouring and a short, thin stubble resulted in severe reduction of trash. In trials 13 and 15 two operations conserved about 30 per cent of the original cover as compared with about 50 to 60 per cent in trials 12 and 14.

Disk-type Implements

The *one-way disk* was used for six trials (Figure 3). Primary tillage with the one-way disk in trials 16 to 21 conserved from 44 to 58 per cent of the original cover and averaged about 50 per cent.

Second-stroke operations with the one-way disk significantly reduced surface cover by slightly more than 50 per cent except for trials 17 and 20, where depth and speed of operation influenced the results. Shallow tillage (about 3 inches deep), conducted at a speed of just over 4 miles per hour in a pulverized soil, resulted in some material that had been buried by the first stroke being thrown to the surface. This action partially offset the

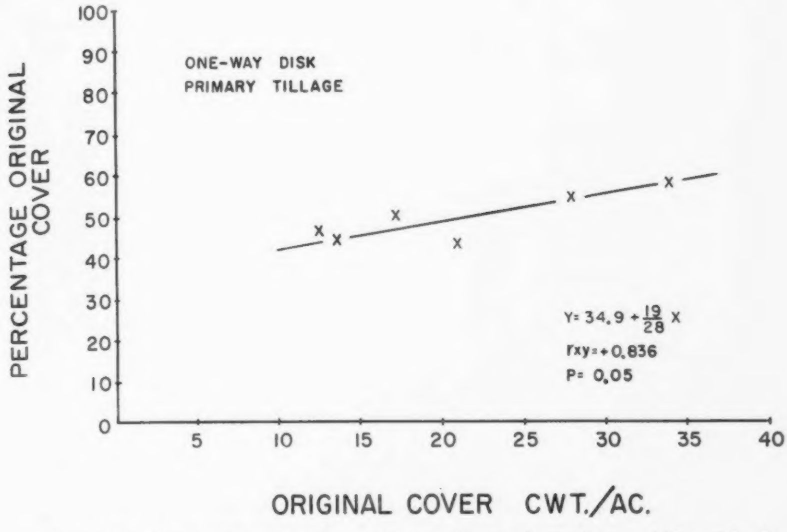

FIGURE 4. Trash conserved after primary tillage of standing stubble with the one-way disk as related to the weight of the original cover.

burial of trash that occurred during the second operation. The third stroke, and in trial 19 the fourth, buried about one-half of the material left by previous work.

A positive correlation was found between the weight of the original cover and the trash conserved by the one-way disk during primary tillage in trials 16 to 21. A line of best fit was calculated, and the data are given in Figure 4. In these trials the crops were harvested with a combine, and, as a result, tall stubble was left on fields that produced a heavy crop and short stubble was left after a light crop was harvested. The stubble heights given in Figure 3 are based on measurements taken in the field, except for the heights given for trials 16 and 17, which were estimated. Weight of cover was used in the correlation study. However, any application of the relationship shown in Figure 4 should be confined to conditions under which weight of cover can be directly associated with height of stubble. In these trials the trash conserved during primary tillage varied from 44 to 58 per cent as weight of cover varied from 1,400 to 3,400 pounds per acre.

The *one-way flexible-disk-harrow* (discer) was used for three trials (Figure 5). In trials 22, 23, and 24 this implement reduced surface cover by about 50 per cent during each operation. Trials 22 and 23 were conducted at a depth of about 4 inches on a stubble of over 2,000 pounds per acre, and trial 24 was conducted at a depth of 2¾ inches on a stubble of about 1,000 pounds per acre. The one-way flexible-disk-harrow buried more of the heavy stubble than of the light stubble during primary tillage as a result of the difference in depth of tillage.

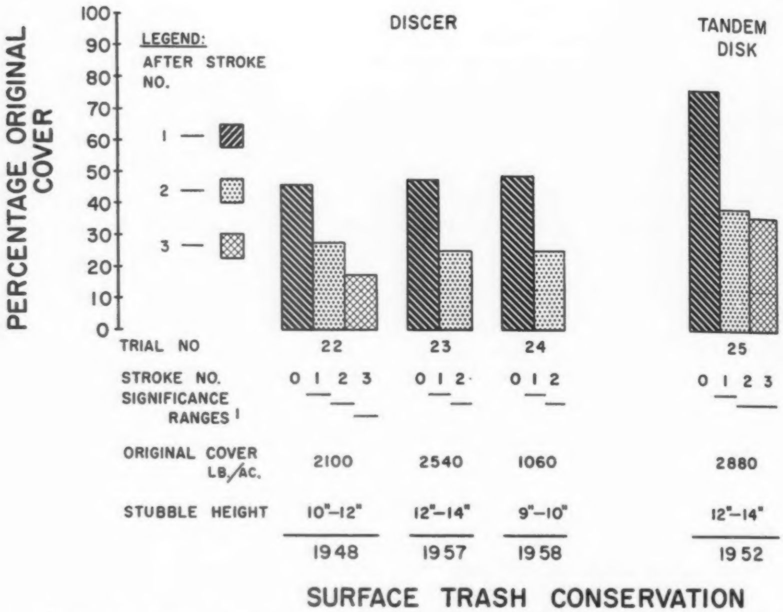

FIGURE 5. Surface trash conserved by the one-way flexible-disk-harrow (discer) and the tandem disk when used for primary and for secondary tillage.

[1]The weight of surface trash cover was not significantly different at the 5 per cent level in any comparison involving 0, 1, 2, or more operations if underlined by the same significance range bar.

The results obtained when the *tandem disk harrow* was used to cultivate a moderately heavy stubble are given in Figure 5 (trial 25). Primary tillage conserved about 75 per cent of the original cover. The third operation conserved most of the surface cover left by the second stroke. The first and third operations were conducted at a depth of about 2 inches. These operations illustrate the usefulness of a shallow disking operation on heavy stubble for conserving surface cover while chopping up straw residue to facilitate tillage and seeding operations. The second stroke was conducted at a depth of about 4 inches and buried about 50 per cent of the existing cover.

The results of field studies in which one implement was used for both primary and secondary tillage are summarized in Figure 6.

The results with the wide-blade cultivator were influenced by soil moisture conditions. The loss of surface trash was greatest when the blade failed to scour properly in moist soil, as illustrated by the average values for the years 1951 and 1955 as compared with those for the years 1950 and 1952. The trash cover reduction pattern of the wide-blade cultivator can be described fairly closely as follows: 15 per cent of the original cover was buried during the first operation, 10 per cent during the second, and 5 per cent or less during each subsequent operation.

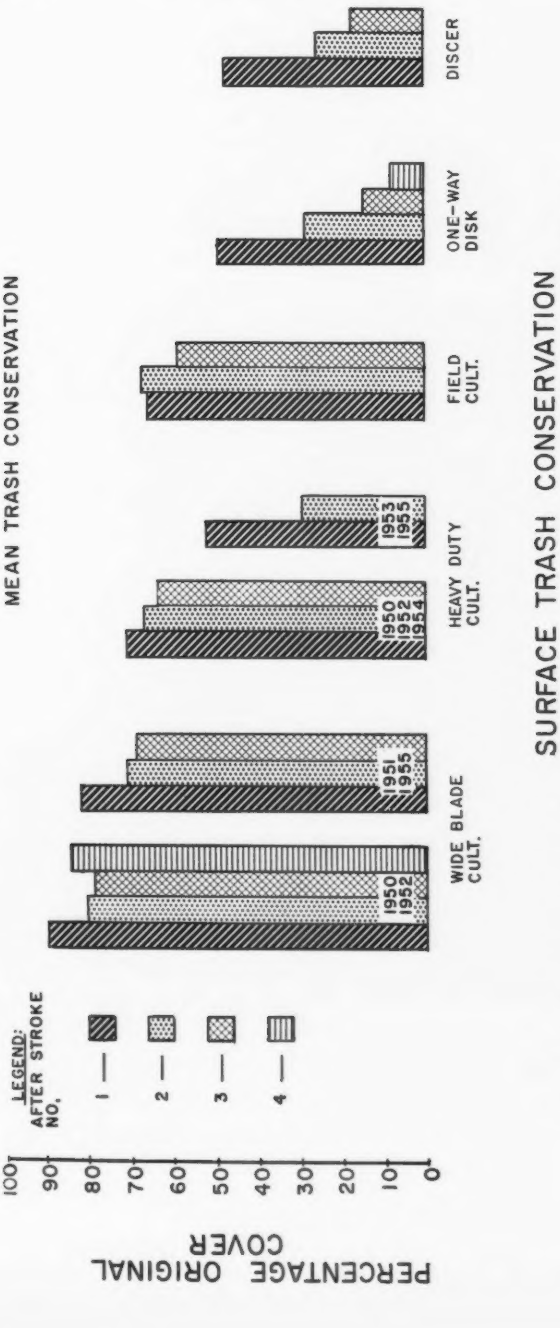

FIGURE 6. Average percentage of trash conserved by sub-surface cultivators and by disk implements.

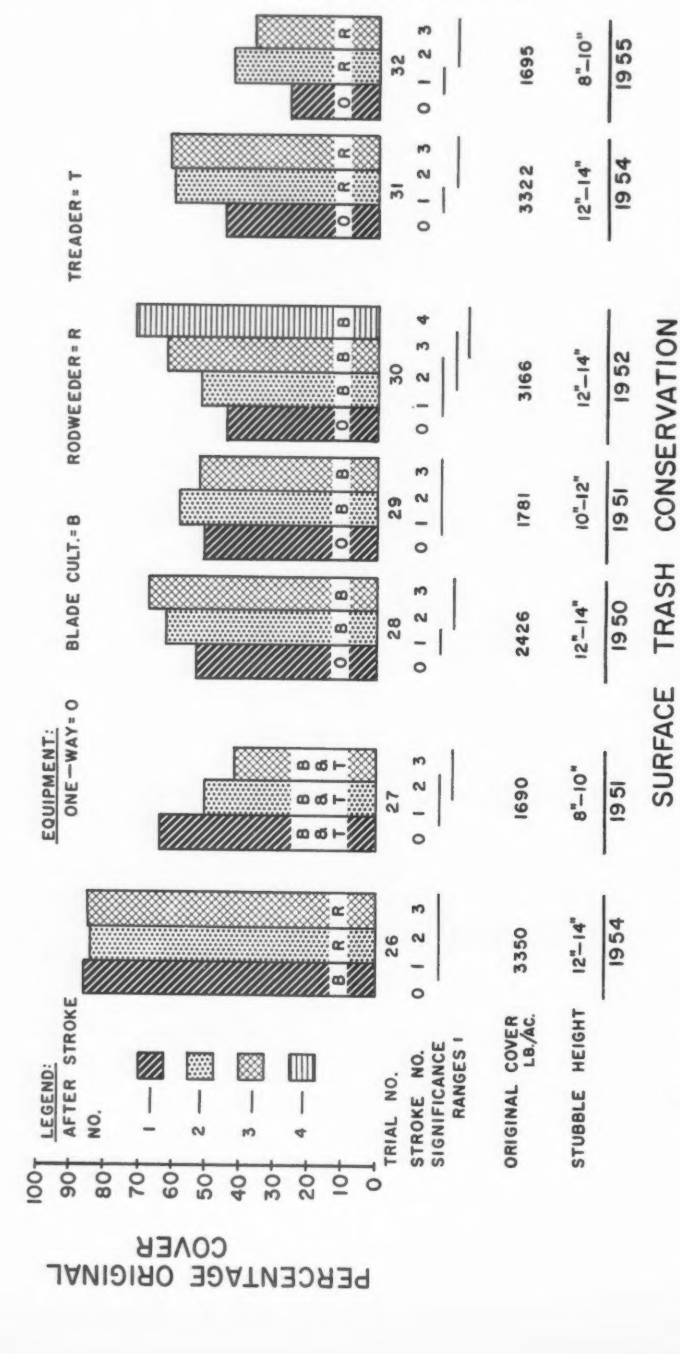

FIGURE 7. Surface trash conserved after primary and secondary tillage with different implements.

[1]The weight of surface trash cover was not significantly different at the **5 per cent** level in any comparison involving 0, 1, 2, 3, or 4 operations if underlined by the same significance range bar.

The trash conservation results with the heavy-duty cultivator varied from high values equivalent to those from the wide-blade cultivator to low values equivalent to those from the one-way disk. Soil moisture and operating factors such as shovel pitch adjustment influenced the results. Reasonably favourable conditions were encountered in the years 1950, 1952, and 1954, while less favourable conditions were encountered in the years 1953 and 1955. In these trials the heavy-duty cultivator buried, on the average, 30 to 50 per cent of the original cover during primary tillage. Second-stroke work buried an additional 5 to 20 per cent of the original cover.

The field cultivator conserved 65, 66, and 68 per cent of the original surface cover after the first, second, and third operations. These results are similar to some obtained with the heavy-duty cultivator.

The one-way disk conserved, on the average, 49, 28, 14, and 8 per cent of the original cover during the first, second, third, and fourth strokes. The average surface trash retention values for the one-way flexible-disk-harrow were 47, 26, and 18 per cent of the original cover for the first, second, and third strokes. These values closely approximate a trash reduction pattern of 50 per cent per stroke. Trash conservation during primary tillage conducted 3 to 4 inches deep with the one-way disk varied from 44 to 58 per cent as weight of cover varied from 1,400 to 3,400 pounds per acre.

PART II — DIFFERENT MACHINES FOR PRIMARY AND SUBSEQUENT TILLAGE

The results of studies of the conservation of surface trash by different tillage implements when used in a tillage sequence are given in Figure 7.

In trial 26 the wide-blade cultivator conserved 86 per cent of the original surface cover during primary tillage. The second and third operations carried out with the rod weeder did not significantly change the weight of surface cover left by the wide-blade cultivator. This conservation pattern is similar to some of the patterns obtained when the wide-blade cultivator was used for both primary and secondary tillage (Figure 1).

In trial 27 the wide-blade cultivator—treader combination conserved 64 per cent of the original cover after one operation and 42 per cent after three operations. It was observed that the treader pressed considerable loose straw into the soil during primary tillage. This action was not so noticeable during the second and third strokes. The unusually wet weather encountered in 1951 likely accelerated decomposition of surface straw (9), and, therefore, slightly less trash was conserved in this trial than would be expected under drier weather conditions. The treader has been recommended (4) for breaking dry residue, for seedbed preparation, and, if operated on the skew, for weed control. The results obtained in this study indicate that where the treader is used to break down residue some reduction of surface trash will occur.

The results of primary tillage with the one-way disk in trials 28 through 32 were influenced by depth of cultivation. In trials 28 and 29, where the disk was operated at a depth of 3 to 4 inches, 54 and 51 per cent of the original 2,426- and 1,781-pound covers remained on the surface. These results are in general agreement with those shown in Figure 3. Trials 30 and 31, conducted 4 to 5 inches deep on covers of 3,166 and 3,322 pounds, conserved 45 per cent on the surface, which was 13 per cent less than was conserved in trial 19 (Figure 3), conducted 3 to 4 inches deep on a 3,400-pound cover. Trial 32, conducted 5 inches deep on a 1,700-pound cover, conserved 26 per cent on the surface. This averaged 22 per cent less trash than that conserved in trials 16 and 20 (Figure 3), which were conducted 3 to 4 inches deep on 2,100- and 1,728-pound covers. These results illustrate the effect of depth of tillage on surface trash conservation with the one-way disk during primary tillage.

Secondary tillage with the blade cultivator lifted significant quantities of trash to the surface in trials 28 and 30. In these trials primary tillage with the one-way disk buried 1,100 and 1,800 pounds of straw, respectively. Two secondary strokes with the blade cultivator lifted 340 pounds of buried material to the surface in trial 28 and 560 pounds in trial 30. Three secondary tillage strokes lifted a total of 860 pounds to the surface in trial 30. In trial 29, which was conducted under wetter soil conditions than the other two trials, secondary work with the blade cultivator did not significantly change the weight of the surface cover. Scouring difficulties with the blade and, possibly, an increased rate of straw decomposition (9) influenced these results. The quantity of trash lifted to the surface by two secondary operations in trials 28, 29, and 30 varied from 1.5 to 17.8 per cent of the original cover and averaged 11 per cent. Three secondary operations lifted a total of 27 per cent of the original cover to the surface in trial 30.

In these studies the use of the one-way disk for primary tillage and the wide-blade cultivator for two secondary tillage operations conserved between 53 and 68 per cent of the original cover. Krall *et al.* (8) reported only 30.7 per cent conservation of trash by a similar combination of implements. They evaluated trash conservation by measurements taken at the beginning of the fallow period and again at the time of seeding winter wheat, but the number of operations was not reported. Greater loss of trash by deterioration undoubtedly occurred during the 1-year measurement period in Montana (8) than during the 2- to 3-month period at Lethbridge.

Secondary tillage with the rod weeder raised buried material to the surface. In trial 31 the one-way disk buried 1,800 pounds of straw during primary tillage. The rod weeder raised 560 pounds of this material to the surface after two secondary operations. In trial 32 the one-way disk buried 1,250 pounds and the rod weeder lifted 200 pounds to the surface after two secondary operations. The quantity of trash lifted to the surface by two secondary operations with the rod weeder varied from 11.8 to 16.8 per cent and averaged 14.3 per cent of the original cover.

CONCLUSIONS

The trash conservation characteristics of some tillage machines have been studied quantitatively, and the results lead to the following conclusions:

The wide-blade cultivator and the rod weeder have very similar trash management characteristics. The use of a tillage sequence involving the wide-blade cultivator alone or in combination with the rod weeder provides maximum trash conservation. A generalized trash reduction pattern for the wide-blade cultivator is 15, 10, and 5 per cent or less of the original cover for the first, second, and third and subsequent operations. If used for two operations following primary tillage with a disk implement, the wide-blade cultivator will return 11 per cent and the rod weeder 14 per cent of the original cover to the surface. This is an important characteristic of these machines.

The conservation of trash by the heavy-duty cultivator is strongly influenced by shovel pitch adjustment and by failure of the shovels to scour in moist soil. In these trials the heavy-duty cultivator reduced surface trash by average values of 30 to 50 per cent during primary tillage and by an additional 5 to 20 per cent during second-stroke work. Trash conservation values almost equivalent to those provided by the wide-blade cultivator can be attained only by careful operation of the heavy-duty cultivator.

The treader can be used behind the wide-blade cultivator to break down long stubble, but almost twice as much trash will be buried by the combination as by the cultivator alone.

The trash conservation characteristics of the one-way disk, the one-way flexible-disk-harrow, and the tandem disk harrow are very similar. Generally, these machines reduce surface cover by about 50 per cent with each operation at a depth of 3 to 4 inches. Continued use of a disk implement in a sequence of operations rapidly buries protective cover. Shallow tillage (3 to 4 inches) conserves more trash than deep tillage (5 to 6 inches). Very shallow work can be carried out to break down long-strawed stubble without burying trash excessively. Trash conservation during primary tillage with the one-way disk is directly related to the weight of the original cover.

The use of one or more machines in a tillage sequence provides a means of regulating surface trash cover on a quantitative basis to meet the needs of good farming practice in different areas. This can be accomplished if the machines are selected and used with an understanding of their trash conservation characteristics.

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DEPTH OF FREEZING AND SPRING RUN-OFF AS RELATED TO FALL SOIL-MOISTURE LEVEL[1]

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ABSTRACT

Studies were conducted at Mandan, North Dakota, to evaluate effects of soil moisture level in the fall and snow depth on depth of freezing and spring run-off. Results showed that soil which was dry in the fall froze faster and deeper than a wet soil. Insulative effects of snow increased with snow depth. In the spring, a dry profile thawed upward to the surface while a wet soil thawed both upward to and downward from the soil surface. Run-off in the spring was less from dry soil. Completion of run-off coincided with frost removal from the dry plots but thawing was not complete in the wet soil until about 10 days after run-off had ceased. Time of run-off completion was the same for wet or dry soils.

In hydrological studies on Ohio watersheds, Post and Dreibelbis (5) studied types of frost as influenced by various covers. They identified and described three types of frost structure, namely: "concrete", "honeycomb", and "stalactite". They found that concrete type frost prevailed under conditions of deep freezing and was impervious to water. The other types of frost occurred with shallow freezing and would allow water penetration. Work by Mosienko (4) in Russia indicated that permeability is good in frozen soils with moisture content less than about 60 per cent field capacity. This worker also indicated that if more than 50 per cent of total soil porosity is free, such soil will be permeable to water irrespective of temperature.

Studies by Crabb (1) using various surface coverings showed that high concentration of moisture occurred at or near the soil surface during the freezing process. He found moisture contents from 23 to 213 per cent in frozen surface soil while unfrozen soil 1 inch beneath the frost was less variable, ranging between 25 and 40 per cent moisture. Garstka (3) proposed that considerable moisture may move to the freezing front from unfrozen subsoil.

Work by Staple and Lehane (6), in Canada, showed that amounts of moisture retained from snow were appreciable in stubble in all years, while there was little retention in bare fallow about 50 per cent of the time. Part of the reason for this difference was attributed to soil temperatures at the 1-foot depth reaching 32°F. in stubble a few days sooner than in fallow.

More recent work by Staple *et al.* (7) has indicated that a negative correlation is probable between fall moisture and moisture conservation. They concluded that each inch of moisture stored in the soil in the fall reduced over-winter conservation by approximately 0.2 inch. These authors also found a very low correlation between moisture conservation and over-winter mean air temperature.

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Crawford and Legget (2) found that undisturbed snow reduced frost penetration. They concluded that frost depth was reduced about 1 foot for each foot of undisturbed snow cover, with, in some cases, as much as 2 feet reduction in frost penetration for each foot of snow.

Much of the research on frozen soils and the influence of various surface covers on depth of soil freezing has been done by highway engineers. Most of the work has not included an evaluation of amounts of water stored in the soil from winter precipitation.

About 20 per cent of the annual precipitation in the Northern Great Plains comes during the winter months, normally as snow. It is generally agreed that only a small amount of moisture is retained by the soil from this precipitation. The amount of water thus lost, principally by spring run-off, can be very important in areas generally plagued with moisture deficiencies.

The study reported here was conducted at Mandan, North Dakota, to determine the effects of soil moisture level in the fall and depth of snow-cover on depth of freezing, and to determine the amount of moisture retained from snowfall as related to soil moisture level in the fall.

MATERIALS AND METHODS

In the fall of 1958, nine field plots, 8 feet wide by 30 feet long, were laid out on Cheyenne fine sandy loam, silty substrata phase. This soil is at present in the process of being reclassified, but a literal description of the soil is as follows: very dark brown friable fine sandy loam, non-calcareous at 0-6 inches; very dark grey friable sandy loam, non-calcareous at 6-14 inches; very dark greyish brown friable fine sandy loam, non-calcareous at 14-28 inches; light greyish brown silty loam, strongly calcareous with some concretions at 28-42 inches; and, greyish brown silty loam, strongly calcareous at 42-62 inches. Slope was 4 per cent with a south exposure. Plot surfaces were smooth and free of vegetation. Metal dikes were placed around each plot and cross dikes were installed to ensure even distribution of water to be applied for establishment of desired soil moisture conditions. The nine plots were separated into three replications of three treatments. Treatments imposed were: M_1 – soil profile dry, natural condition; M_2 – soil wet to a depth of 18 inches (3 inches of water applied); and M_3 – soil wet to a depth of 4 feet (8 inches of water applied). These treatments hereafter will be referred to as "dry", "medium" or "wet" moisture levels. Soil moisture content in the dry plots was approximately at wilting percentage to a depth of at least 5 feet. After water application was completed, late in October, the metal dikes were moved inward, leaving a plot size of 4 feet by 30 feet. Thus, lateral movement effects should have been minimized. The plots were then covered with plastic sheeting until the onset of winter weather.

Provisions were made to measure run-off by placing metal flumes, which were directed into barrels, at the lower end of each plot. Copper-constantan thermocouples were installed at depths of 0, 3, 6, 12, 18, 24, 36, 48, 60, and 72 inches in each treatment of one replication. A thermo-

couple, properly shaded from the sun, for measuring air temperature was placed at 5 feet above ground level. Thermocouples were later (December 29) placed at 1, 4, and 7 inches above the soil surface at one location for the purpose of measuring temperature in the snow. Temperature measurements were taken continuously for a 24-hour period at weekly intervals using an electronic strip-chart recorder. Temperature readings were taken at less than weekly intervals during the periods of freezing and thawing. Two access tubes for use with a neutron moisture meter were placed in each plot of one replication. Soil moisture measurements were taken at bi-weekly intervals until after thawing was complete. Snow was left in place on all plots.

In the fall of 1959, the nine plots plus one additional plot were treated in essentially the same manner as described above. One difference was that the medium moisture level plots were wetted to a depth of 24 inches rather than 18 inches. Also, thermocouples were installed at depths of 0, 6, 12, 18, 30, 48, and 60 inches in each plot, and at 1, 4, 8, 16, and 60 inches above the soil surface at one location. The following imposed conditions were considered as treatments: M_1 — soil profile dry, natural condition; M_2 — soil moisture to a depth of 2 feet; M_3 — soil moisture to a depth of 4 feet; C_1 — surface bare (kept free of snow); C_2 — naturally occurring snowfall; C_3 — naturally occurring snowfall with about the same amount added or approximately twice normal (extra-normal); C_4 — surface kept bare until about February 1 and then 2 feet of snow added. Thus, there were ten plots with treatments M_1C_1, M_1C_2, M_1C_3, M_2C_1, M_2C_2, M_2C_3, M_2C_4, M_3C_1, M_3C_2, and M_3C_3, without replication. Run-off was not measured on plot M_2C_4.

Moisture samples for total soil moisture by gravimetric determination were taken each fall after moisture levels had been established and before the soil froze. Gravimetric samples were again taken after spring run-off was complete. Also, moisture content of the snow-pack was determined before run-off.

A temperature of 32°F. was used as the dividing point between presence or absence of frost. Thus, as the soil cooled it was not considered frozen until the temperature at that point was less than 32°F.; and as the soil warmed in the spring, it was not considered thawed until the temperature at a given point was about 32°F. In this manner, it is felt that some allowance was made for supercooling or latent heat effects. A frozen soil is generally considered to be one in which the liquid phase has changed to solid state. Freezing may be affected by moisture and salt contents. Periodic physical examination of the profiles was not feasible. Therefore, further reference to "frozen" soil is based entirely upon temperature and not upon the physical condition of water in the soil.

RESULTS AND DISCUSSION

Periodic measurements of air and ground surface temperatures and snowfall accumulation taken during the 1958-59 winter season are presented in Figure 1.

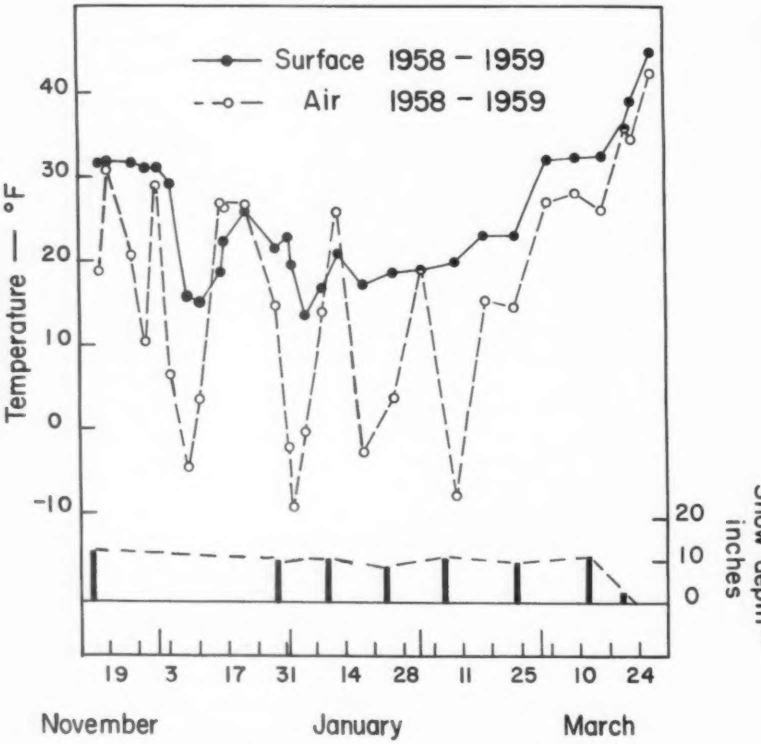

FIGURE 1. Air and ground surface temperatures and snowfall accumulation as measured periodically during the 1958-59 winter. Each point is the average temperature for a continuous 24-hour period.

The first snowfall of the 1958-59 season occurred November 15. A 12-inch accumulation of snow was measured, with distribution very uniform, over the entire experimental area. Warm temperatures, immediately after snowfall had ceased, caused enough melting for the top 6 inches of the dry plots to become wet. Freezing temperatures prevailed from November 17 until spring with the lowest recorded air temperature being −39°F. A number of small storms kept the snow accumulation on the plots at 10-12 inches during December and January. Snow depth was 11 inches just prior to spring thaw.

Measurements of air and ground surface temperatures and snowfall accumulation taken periodically during the 1959-60 winter season are presented in Figure 2.

Weather conditions were more erratic during the 1959-60 winter, with some cycles of freezing and thawing during the freezing period in the fall and the thawing period in the spring. Snow depth was 13 inches just prior

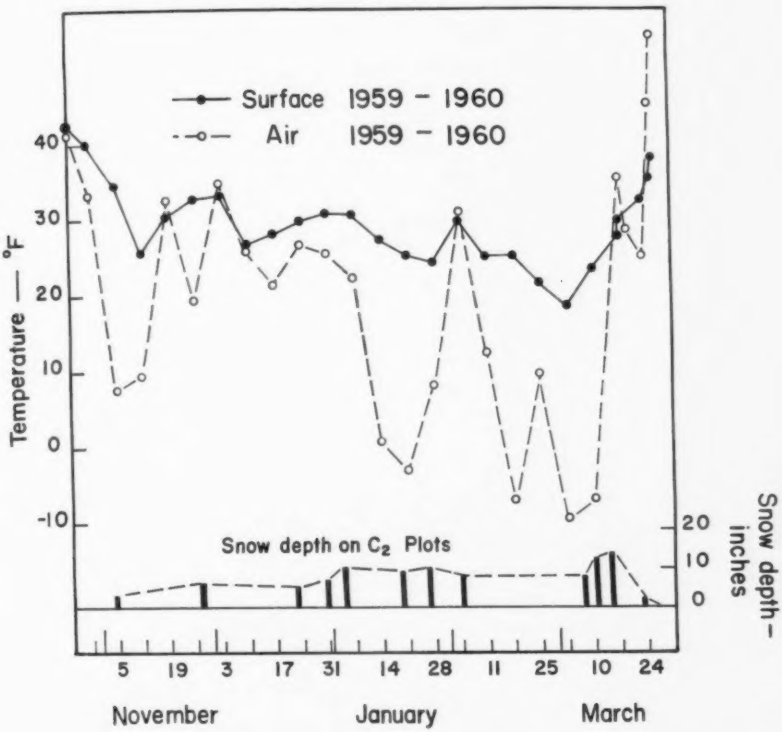

FIGURE 2. Air and ground surface temperatures and snowfall accumulation as measured periodically during the 1959-60 winter. Each point is the average temperature for a continuous 24-hour period.

to spring thaw. The lowest recorded temperature was –22°F. Snow drifting was not a problem in either year.

Numbers of degree-days below freezing were calculated from the data shown in Figures 1 and 2. The degree-days for any one day is the difference between the average daily air temperature and 32°F., plus and minus signs being used to differentiate between freezing degree-days or thawing degree-days. Results were not conclusive and an empirical relation for prediction of rate and depth of soil freezing could not be established.

The curves given in Figure 3 show the differences in depth and rate of freezing for soils at different moisture levels for the 1958-59 winter. The medium moisture level is not included, but the curve would lie between the two presented. It is shown that a dry soil will freeze faster and deeper than a moist soil, due primarily to the differences in heat capacity. The two curves are initially the same since the top 6 inches of the dry profile was wet.

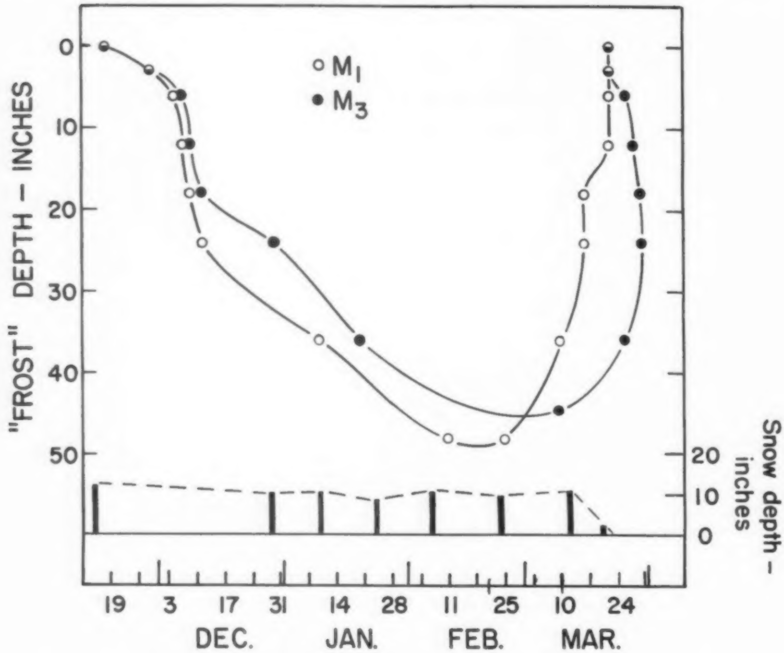

FIGURE 3. Depth of freezing temperature as a function of time for a wet (M_3) soil or dry (M_1) soil during the 1958-59 winter.

It is of interest to note in Figure 3 that the dry soil showed thawing from lower depths upwards to the surface while the wet soil showed thawing both upward to and downward from the soil surface. In both cases, thawing at the surface coincided with completed thawing of snow cover. Excavation and probing indicated that "concrete" type frost was predominant.

Data from the 1959-60 winter were plotted in Figure 4. Again it is shown that a dry soil tends to freeze deeper and faster than a wet soil. Insulating effects of snow cover, comparable to the findings of Crawford and Legget (2), are also nicely shown. These data do not show the difference in thawing pattern between wet and dry soils as exhibited by data from the previous year. One reason might be that the 1959-60 winter season was milder than that of the previous winter. A second reason might be that the freezing and thawing cycles during the 1959 fall allowed the top 12 to 15 inches to become wet.

Data from neutron meter readings (1958-59 winter) showed a marked increase in soil moisture in the 3- and 6-inch depths for all moisture level treatments until early December. The increase in surface-soil moisture was due to some melting of snow immediately after the first snowfall. Smaller

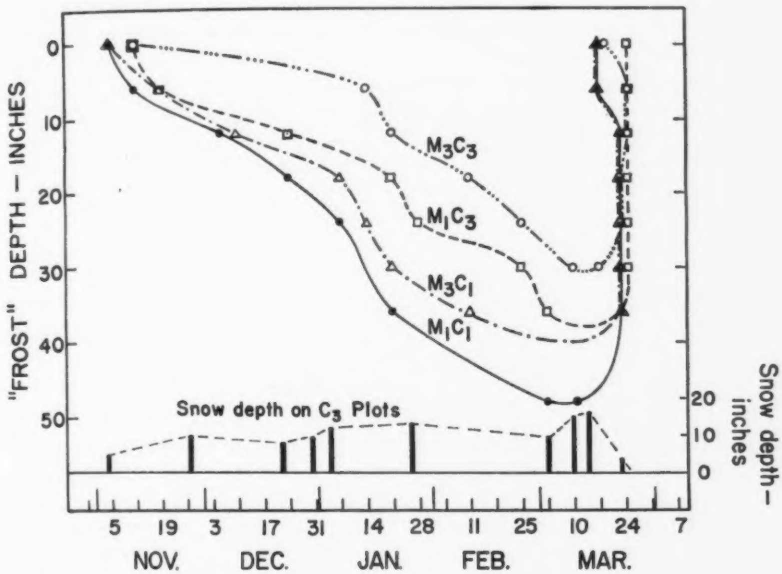

FIGURE 4. Depth of freezing temperature as a function of time for wet (M_3) or dry (M_1) soils under no (C_1) or extra-normal (C_3) snow cover during the 1959-60 winter.

increases occurred under the wet and medium treatments at some of the lower depths. Following that time only minor changes occurred in soil moisture.

Freezing of the soil apparently had little, if any, effect on the accumulation of moisture at the depth of freezing, since the increases in moisture at the freezing depth could not be accounted for by decreases in moisture from the lower depths. It is possible that there was no change in soil moisture status during freezing due to the rapidity with which the profiles were frozen during the fall of 1958. Neutron readings were not taken during the second winter.

Data from the gravimetric samplings, snow-pack measurements and run-off for the 1958-59 winter were used to calculate the information in Table 1. There appears to be some association between fall moisture level and both gain in soil moisture and run-off of snow-melt. The values for medium and high moisture levels in Table 1 are just the reverse of what might be expected. The run-off measurements could be taken quite accurately, but soil moisture and snow-pack moisture measurements are subject to error. The differences between levels for either moisture gain or percentage run-off are not statistically significant at the 5 per cent level; the coefficients of variation are 27 per cent and 14 per cent respectively. The implications of the trend in moisture change will be discussed later.

TABLE 1.—CHANGES IN SOIL MOISTURE AND PERCENTAGE OF SNOW-PACK MOISTURE LOST BY RUN-OFF DURING THE 1958-59 WINTER

Soil moisture level	Gain in soil moisture, inches[1]	Percentage of water in snow lost by run-off[1]
Low	1.50	48
Medium	0.36	81
High	0.87	72

[1]Average of 3 plots

TABLE 2.—CHANGE IN SOIL MOISTURE AND PERCENTAGE OF SNOW-PACK MOISTURE LOST BY RUN-OFF DURING THE 1959-60 WINTER

Soil moisture level	Snow cover treatment	Gain in soil moisture, inches	Percentage of water in snow lost by run-off
Low	Bare	−0.53	—
	Normal	0.68	77
	Extra-normal	0.70	90
Medium	Bare	−0.48	—
	Normal	−0.82	84
	Extra-normal	0.90	88
High	Bare	−1.57	—
	Normal	1.32	77
	Extra-normal	0.11	85
Medium	Bare until February 1	1.46	—

Similarly, data from the 1959-60 winter were used to calculate the values given in Table 2. It is of interest to note the apparent loss of soil moisture from the bare plots, indicating the importance of surface cover during the winter months. However, the plot left bare until February 1 and then covered with snow showed a substantial gain in soil moisture. It is felt that there must have been more than usual sampling error involved for both the medium-normal and high extra-normal plots.

Measurements of peak rate of run-off were taken during the 1960 spring thaw. It was found that peak run-off occurred early in the thaw period for the normal snow cover and higher moisture level plots; but peak run-off came later in the thaw period for the extra-normal snow cover and low moisture level plots.

The percentage run-off was higher for the 1959-60 winter period than for the previous winter. The implication from the 2 years' data is that the amount of run-off may be governed to some extent by soil moisture conditions in the surface 12 to 15 inches.

From the temperature data in the figures and the moisture data in tables, it is apparent that soil moisture conditions in the fall and general weather conditions of the winter will govern depth of freezing, spring run-off and

moisture retention. Even though it appears there may be less run-off from a plot which is dry in the fall, the gain in soil moisture is not of sufficient magnitude to bring the moisture level of a dry plot up to the moisture level of a wet plot. Thus, attempts to increase storage of winter precipitation by maintaining the soil in a dry state in the fall, say by fall cropping, may not be advantageous. The amount of run-off and erosion in the spring may be less from such a practice, but the quantity of soil moisture available to the succeeding crops may be reduced.

After the soil begins to thaw in the spring, the period required for complete thawing is rather short. However, it is during this short period that a large part of the winter precipitation is lost. Almost any means of holding snow-melt in place until it can infiltrate the soil would be of advantage as regards soil moisture storage. One practice which at present appears promising for holding snow-melt is the level or conservation bench terrace.

CONCLUSIONS

Results indicated that dry soils freeze deeper and faster than wet soils and that, following a severe winter, dry soil tends to thaw from the lower depths toward the surface while a wet soil tends to thaw both upward toward the surface and downward from the surface. There was also an indication that run-off tends to be less from a dry soil providing the surface 12 to 15 inches does not become wetted before the soil freezes. Results showed that not only is snow an effective insulator but there may also be considerable loss of soil moisture from soil which is bare during the winter months. Gains in soil moisture from snow-melt in the spring are not sufficient to bring a soil which was dry in the fall up to the same moisture level as that of a soil which was wet in the fall. Thus, under the conditions studied, most practices which enhance infiltration of snow-melt will be desirable as far as soil moisture conservation is concerned.

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THE CHARACTERISTICS OF DIFFERENT GENETIC SOIL TYPES IN THE NEWDALE SOIL ASSOCIATION OF MANITOBA[1]

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ABSTRACT

The Newdale Soil Association of Manitoba consists of a number of genetic soil types which are the result of local variations in relief, drainage and vegetation. Seven of these soil types were examined in the field and studied in the laboratory in an attempt to relate their characteristics to the factors responsible for their formation.

It was found that the depth of the solum of these soils increased the farther down the slope the soil occurred, because of greater amounts of water entering the soil and the resultant cooler, moister soil climate. The per cent of exchangeable hydrogen also followed this trend. Where local soil-climatic conditions favoured the invasion of trees into the grassland area, the soils exhibited considerable degradation. This was revealed by the marked clay illuviation, the greater per cent of exchangeable hydrogen and the lower amount of organic carbon in the soils found under tree vegetation. Internal drainage had an important influence on the type of soil developed in the depressional areas.

INTRODUCTION

Standard text-books on soil science usually list the main soil-forming factors as climate, biosphere, parent material, topography and time. Ellis (7) suggested that the topography factor involves relief, slope exposure and surface drainage, but that internal drainage can be influenced by factors other than topography. He also proposed the addition of another factor, namely culture or the work of man. The effects that each of these factors has on soil formation are not easily defined because of the interdependence of the factors. The roles of the various factors in soil formation have been described in detail by Jenny (9), Joffe (10) and others.

The Newdale Soil Association in Manitoba (6) is well suited to a study of the effect of local variations in relief, drainage and vegetation on the development of various genetic soil types. Several of the soil-forming factors can be considered as being constant within the area. The parent material of the Newdale Soil Association is a relatively uniform glacial till, loam in texture and containing 15-20 per cent $CaCO_3$ (5, 6). It can be assumed that all the glacial till of the area was exposed to the soil-forming factors at about the same time and, therefore, that the various soils are of the same chronological age. The regional climate is constant over the area. Thornthwaite's (16) method was used to calculate Precipitation Effectiveness (P-E) Index and Temperature Efficiency (T-E) Index values from the climatic records of five reporting stations within the area. The P-E Index values varied from 35 to 46 and the T-E Index values from 33 to 36. Thus, according to the Thornthwaite's criteria, the regional climate is subhumid and temperate. The average annual rainfall is 16-18 inches and the annual mean temperature is 32-34°F.

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[1]Contribution from Department of Soil Science, University of Manitoba. This paper is part of a thesis submitted by the author in partial fulfilment of requirements for the M.Sc. degree at the University of Manitoba. Presented at the 1st Annual Convention, Canadian Society of Soil Science, Edmonton, Alta., June 1955.

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The topography of the area is generally undulating with numerous undrained depressions. Therefore, as Ellis (7) pointed out, the knolls from which water run-off occurs tend to be locally arid while the depressions where the run-off water accumulates tend to be locally humid. Furthermore, northern and eastern slope exposures tend to be cooler than southern and western exposures and this results in differences in soil climate. The variations in soil climate are reflected by variations in the indigenous vegetation.

The major portion of the area is well drained upland and here the dominant indigenous vegetation (6) is tall prairie grasses (*Agropyron* spp., *Elymus* spp., *Poa* spp., *Andropogon* spp., *Festuca* spp.). Islands of aspen (*Populus tremuloides*) occur throughout the area especially in the more humid sites such as the non-saline depressions and on northern and eastern exposures. Balsam poplar (*P. balsamifera*) and willows (*Salix* spp.) as well as reeds (*Typha* spp.) and sedges (*Carex* spp.) occur in the less well-drained, non-saline sites. The proportion of the area covered by tree vegetation increases from south to north with increasing altitude, increasing moisture effectiveness and decreasing temperature efficiency. Halliday (8) described this area as a transition zone between the Grassland region and the Boreal Forest.

The dominant soil series, which occurs on the well-drained sites, was formed under grass vegetation. This soil (Figure 1, No. 2) was described by Ellis (7) as a Northern Blackearth and more recently by the Manitoba Soil Survey (6) as a Slightly Degrading Blackearth. In the 1955 Preliminary Outline of the Classification of Canadian Soils (13) this soil falls into the Modal (now orthic) Black group. Several other genetic soils, resulting from variations in relief, drainage and vegetation, occur in association with this dominant soil. The study reported herein was undertaken to characterize the main genetic soils encountered in the Newdale Soil Association and to relate their characteristics to the factors responsible for their formation.

MATERIALS

For this study, seven genetically different soils were selected and sampled by horizon depths. Because most of the area was under cultivation, it was necessary to select these profiles from sites over a distance of 15 miles in order to obtain virgin soils which were representative of the respective topographical positions. Three of the soils, the Shallow Black, the Orthic Black and the Gleyed Black (Figure 1, No. 1, 2, 3) represented a topo-sequence of non-degraded (or slightly degraded) soils formed under grass vegetation on the knoll, the upper and the lower slope positions respectively. The Dark Grey Wooded and the Gleyed Dark Grey Wooded soils (Figure 1, No. 5, 6) represented a topo-sequence of degraded soils formed respectively on the upper slope position under poplar (*Populus* spp.) vegetation and on the lower slope position under poplar and willow (*Salix* spp.) vegetation. The Calcareous Meadow and the Grey Wooded Gley soils occurred in depressional positions; both of these soils had an indigenous vegetation of sedges (*Carex* spp.) and associated hydrophytic herbaceous

TABLE 1.—PROFILE CHARACTERISTICS OF THE NON-DEGRADED (OR SLIGHTLY DEGRADED) SOILS

1. SHALLOW BLACK—formed on knoll position

Main horizons	Depth (in.)	Dominant texture	Dominant structure	Dominant dry colour
A_1	0-3	loam	granular	Very dark grey (10 YR 3/1)
B	3-8	clay loam	nuciform	Dark greyish brown (10 YR 4/2)
C_{Ca}	8-20	clay loam	amorphous-weak granular	Light brownish grey (2.5 Y 6/2)
C	20+	loam	amorphous-weak granular	Olive grey (5 Y 6/2)

2. ORTHIC BLACK (Newdale Series)—formed on upper slope position

Main horizons	Depth (in.)	Dominant texture	Dominant structure	Dominant dry colour
A_1	0-7	loam	granular	Very dark grey (10 YR 3/1)
B	7-17	clay loam	nuciform	Dark greyish brown (10 YR 4/2)
C_{Ca}	17-32	clay loam	amorphous-weak granular	Light brownish grey (2.5 Y 6/2)
C	32+	loam	amorphous-weak granular	Pale brown (10 YR 6/3)

3. GLEYED BLACK—formed on lower slope position

Main horizons	Depth (in.)	Dominant texture	Dominant structure	Dominant dry colour
A_1	0-6	loam	granular	Very dark grey (10 YR 3/1
B	6-24	loam	nuciform to granular	Greyish brown-brown 2.5Y 4/2-10YR5/3)
C_{Ca}	24-32	clay loam	amorphous-weak granular	Light grey (10 YR 7/2)
C	32+	loam	amorphous-weak granular	Yellowish brown (10 YR 5/4)

4. CALCAREOUS MEADOW—formed in depression position

Main horizons	Depth (in.)	Dominant texture	Dominant structure	Dominant dry colour
A_1	0-8	loam-silt loam	crumb	Black (10 YR 2/1)
C_{Ca}	8-15	clay*	amorphous-weak granular	White (10 YR 8/1)
C	15+	loam	amorphous-weak granular	Light olive grey (5 Y 6/2)

*Due to an accumulation of $CaCO_3$

TABLE 2.—PROFILE CHARACTERISTICS OF THE DEGRADED SOILS

5. DARK GREY WOODED—formed on upper slope position

Main horizons	Depth (in.)	Dominant texture	Dominant structure	Dominant dry colour
0	0-2		leaf mat	
A_1	2-6	loam	granular	Dark greyish brown (10 YR 3/2)
A_2	6-9	loam	fine platy	Pale brown (10 YR 6/3)
B_1	9-12	loam	nuciform	Greyish brown (10 YR 5/2)
B_2	12-16	loam-clay loam	nuciform	Dark greyish brown (10 YR 3/2)
B_3	16-25	silt loam-loam	nuciform	Yellowish brown (10 YR 5/4)
C_{Ca}	25-30	silt loam	amorphous-weak granular	Very pale brown (10 YR 7/4)
C	30+	loam	amorphous-weak granular	Very pale brown (10 YR 8/3)

6. GLEYED DARK GREY WOODED—formed on lower slope position

Main horizons	Depth (in.)	Dominant texture	Dominant structure	Dominant dry colour
0	0-3		leaf mat	
A_1	3-6	loam	granular	Dark greyish brown (10 YR 4/2)
A_2	6-8	loam	fine platy	Greyish brown (10 YR 5/2)
B_1	8-10	clay loam	nuciform	Greyish brown (10 YR 5/2)
B_2	10-17	clay loam	nuciform	Brown-dark greyish brown (10 YR 5/3-10 YR 4/2)
B_3	17-20	clay loam	granular	Yellowish brown (10 YR 5/4)
C_{Ca}	20-31	clay loam	amorphous-weak granular	Very pale brown (10 YR 7/4)
C	31+	loam	amorphous-weak granular	Very pale brown (10 YR 8/4)

7. GREY WOODED GLEY—formed in depression position

Main horizons	Depth (in.)	Dominant texture	Dominant structure	Dominant dry colour
0	0-3		leaf mat	
A_1	3-4	silt loam	granular	Dark grey (10 YR 4/1)
A_2	4-11	silt loam	fine platy	Light grey (10 YR 7/2)
B_1	11-14	clay loam	nuciform	Dark greyish brown (10 YR 3/2)
B_2	14-30	clay	massive-nuciform	Dark grey (10 YR 4/1)
B_3	30-34	clay loam	amorphous-weak granular	Greyish brown (10 YR 5/2)
C	34+	loam	amorphous-weak granular	Pale brown (10 YR 6/3)

*Due to an accumulation of $CaCO_3$

plants. Willows also occurred on the Grey Wooded Gley soil. The relatively high organic carbon content of the A_1 horizon, the presence of $CaCO_3$ near the surface, and iron staining in C_{ca} horizon indicated that the Calcareous Meadow soil had been subjected to periodic saturation by ground water. In contrast, the Grey Wooded Gley soil appeared initially to have had better internal drainage, although the very heavy B horizon is now relatively impervious as indicated by the iron-stained A_2 horizon.

Profiles 2 and 3 were taken from two positions on the same slope and profiles 5 and 7 were taken from two positions on another slope. Profiles 1, 4 and 6 were taken from three separate locations. The seven soils used in this investigation are briefly characterized in Tables 1 and 2 and illustrated in Figure 1. The profiles are arranged in Figure 1 in the order in which they are normally found in relation to slope; the Shallow Black soil occurs at the summit, the degraded soils progressively lower on northern and eastern slope exposures and the non-degraded soils progressively lower on southern and western slope exposures.

METHODS

The procedure used for the mechanical analysis was a modification of the method of Kilmer and Alexander (12). In this procedure the organic matter was removed with H_2O_2 but the inorganic carbonates were not removed. Inorganic carbon was determined by boiling the soil sample in 1 : 1 HCl and measuring the amount of CO_2 evolved by collecting it in ascarite. The results were expressed as per cent $CaCO_3$ equivalent. Total carbon was measured using modifications of methods proposed by Adams (1) and Waynick (17). Organic carbon was obtained by the difference between total and inorganic carbon. The pH values were determined using Doughty's (4) method. Nitrogen was measured by a modified Kjeldahl-Gunning-Arnold method (2) in which K_2SO_4 and $CuSO_4$ and Hg were employed as catalysts. The exchangeable bases were extracted from the soil with neutral N ammonium acetate according to Schollenberger's method (Kelley 11). Exchangeable cations were not determined on the C_{ca} and C horizons because of the presence of free $CaCO_3$ in these horizons. Exchangeable calcium was determined by precipitation as the oxalate salt and by titration with $KMnO_4$. Exchangeable magnesium was precipitated with sodium ammonium phosphate, redissolved in standard acid and back titrated with standard NaOH. Exchangeable sodium and potassium were measured with the Beckman Model DU Flame Photometer using a calcium-free extract which was 0.2 N with respect to HCl. Exchangeable hydrogen was determined by titrating an aliquot of a 0.5 N barium acetate extract with standard NaOH according to Parker's (14) method. The assumed cation exchange capacity was obtained by summation of the quantities of the individual cations obtained by the various methods. The cations were expressed as a per cent of the cation exchange capacity thus calculated.

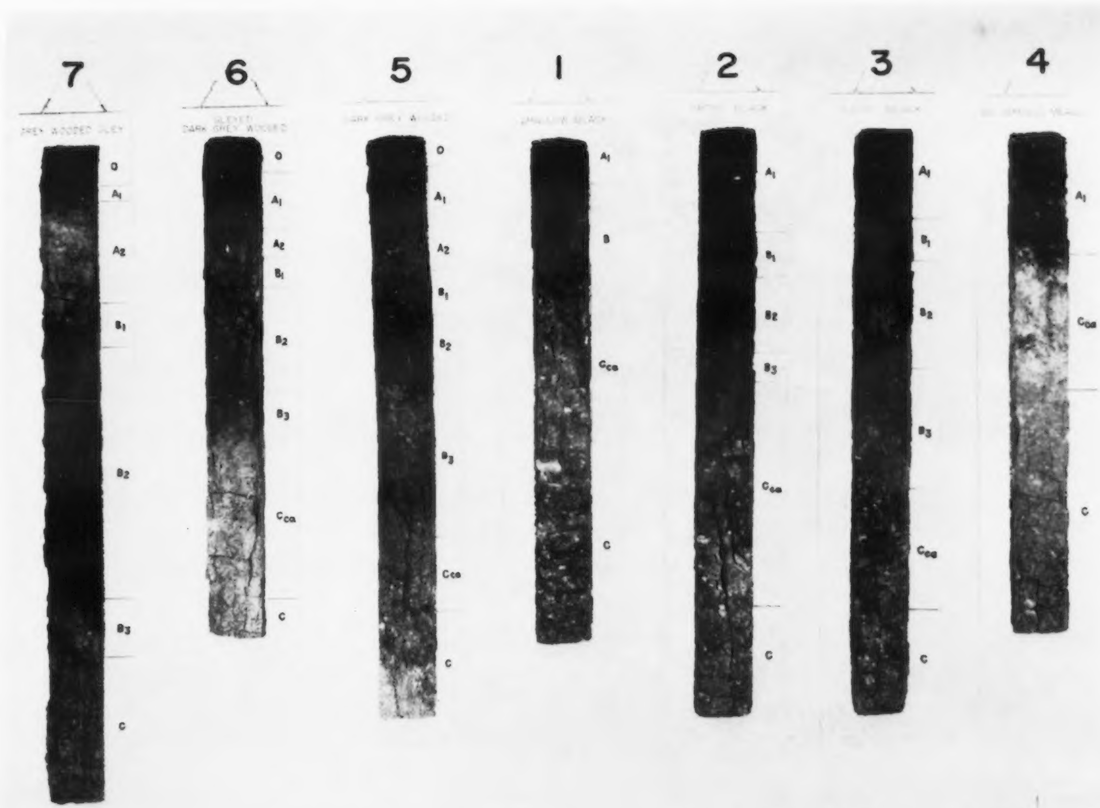

FIGURE 1. Seven different genetic soil types which occur in the Newdale Soil Association of Manitoba.

RESULTS AND DISCUSSION

The results of the mechanical analyses, the inorganic carbonate, the organic carbon and the nitrogen determinations are shown in Table 3.

TABLE 3.—MECHANICAL COMPOSITION, CALCIUM CARBONATE[1], ORGANIC CARBON AND NITROGEN CONTENT OF SOILS
(in per cent of oven dry weight)

Soil	Profile no.	Horizon	Depth	Sand 2.0-0.05 mm.	Silt 0.05-0.002 mm.	Clay <0.002 mm.	$CaCO_3$[1]	Organic carbon	Nitrogen
Shallow Black	1	A_1	0-3	40	38	22	0.1	5.2	0.44
		B	3-8	42	29	29	0.3	1.0	0.11
		C_{Ca}	8-20	35	35	30	20.5	—	—
		C	20+	50	32	18	17.0	—	—
Orthic Black (Newdale Series)	2	A_1	0-7	40	37	23	0.4	5.4	0.44
		B_1	7-10	32	39	29	0.3	3.1	0.28
		B_2	10-15	32	35	33	0.1	1.3	0.12
		B_3	15-17	34	38	28	4.9	1.1	0.09
		C_{Ca}	17-32	35	35	30	20.8	—	—
		C	32+	38	38	24	15.7	—	—
Gleyed Black	3	A_1	0-6	41	36	23	0.2	4.5	0.37
		B_1	6-9	48	29	23	0.0	1.3	0.09
		B_2	9-16	44	29	27	0.0	0.6	0.08
		B_3	16-24	50	29	21	6.5	0.5	0.08
		Cca	24-32	36	34	30	20.2	—	—
		C	32+	37	36	27	16.6	—	—
Calcareous Meadow	4	A_1	0-8	24	49	27	3.5	9.7	1.00
		C_{Ca}	8-15	24	28	48	43.0	—	—
		C	15+	37	37	26	15.6	—	—
Dark Grey Wooded	5	0	0-2	—	—	—	1.0	26.0	1.70
		A_1	2-6	38	47	15	0.1	3.6	0.27
		A_2	6-9	42	44	14	0.0	0.5	0.07
		B_1	9-12	33	42	25	0.1	0.5	0.07
		B_2	12-16	25	47	28	0.1	0.5	0.07
		B_3	16-25	29	51	20	2.4	0.3	0.05
		C_{Ca}	25-30	14	67	19	24.2	—	—
		C	30+	49	33	18	17.2	—	—
Gleyed Dark Grey Wooded	6	0	0-3	—	—	—	1.1	20.0	1.35
		A_1	3-6	36	47	17	0.1	2.7	0.21
		A_2	6-8	34	45	21	0.3	0.8	0.10
		B_1	8-10	31	39	30	0.1	0.8	0.08
		B_2	10-17	32	32	36	0.1	0.4	0.06
		B_3	17-20	36	33	31	9.7	0.5	0.07
		C_{Ca}	20-31	32	34	34	26.3	—	—
		C	31+	36	38	26	18.6	—	—
Grey Wooded Gley	7	0	0-3	—	—	—	0.7	15.4	1.09
		A_1	3-4	18	64	18	0.2	7.8	0.63
		A_2	4-11	22	64	14	0.0	0.6	0.07
		B_1	11-14	29	35	36	0.1	0.4	0.06
		B_2	14-30	28	30	42	0.3	0.2	0.05
		B_3	30-34	36	32	32	0.3	0.2	0.04
		C	34+	36	38	26	15.8	—	—

[1]Inorganic carbon converted to $CaCO_2$

The mechanical analyses revealed that the C horizons of profiles 2, 3, 4, 6 and 7 had remarkably similar contents of sand, silt and clay. Profiles 1 and 5 had higher contents of sand in the C horizons. The mechanical analysis results indicated that there had been a small amount of illuviation in the grassland profiles (1, 2, 3). Similar results were reported by Ehrlich (5) and Barr (3). The apparent accumulation of fine material in the C_{ca} of the Calcareous Meadow soil (profile 4) was largely due to an accumulation of calcium carbonate deposited by ground water. The degraded soils (profiles 5, 6 and 7) exhibited more pronounced illuviation than the non-degraded soils as revealed by the greater difference between the clay contents of the A and B horizons of the former compared to the latter.

The data for the sand and silt contents of these profiles also are noteworthy. The amounts of sand and silt were nearly equal in the surface horizons of the non-degraded soils (profiles 1, 2 and 3). However, in the degraded soils (profiles 5, 6 and 7) the surface horizons contained considerably higher amounts of silt than sand. Eluviation of clay from the surface horizons of the degraded soils would be expected to result in a concomitant increase in the percentage of sand and silt. Since there was an increase in only the silt content, it is possible that part of the sand fraction has been weathered to silt-sized particles. On the other hand, the higher proportion of silt may have been due to initial variations in the glacial till.

The upper horizons of the soils formed under grass (profiles 1, 2 and 3) had very low contents of $CaCO_3$. The zone of carbonate accumulation in these soils occurred at increasingly greater depths with increasing distance down the slope because of greater amounts of water having entered the soil. The A and B horizons of the three degrading profiles (5, 6, and 7) also contained negligible amounts of $CaCO_3$. As in the soils formed under grass, the depth to the C_{ca} horizon generally increased with increasing amounts of water having entered the soil. The Calcareous Meadow soil apparently had restricted internal drainage and, therefore, had been subjected frequently to saturation by ground water. This was evident from the $CaCO_3$ which occurred in the A horizon and the extremely calcareous C_{ca} horizon.

The three soils formed under grass vegetation and the Calcareous Meadow soil contained relatively high amounts of organic carbon and nitrogen in the A_1 horizons. This was particularly true of the Calcareous Meadow soil where the high moisture conditions had resulted in lush growth of sedges and had probably resulted in decreased decomposition of the organic residues. There was a sharp reduction in the content of organic carbon and nitrogen in the B horizons. The degraded soils all had leaf-mat (0) horizons which were very high in organic carbon and nitrogen. However, the A_1 horizons of the degraded soils were thinner than the A_1 horizons of the non-degraded soils and they contained considerably lower amounts of organic carbon and nitrogen. The A_2 horizons of the degraded soils were very low in organic carbon and nitrogen. Similar results were reported by Ehrlich (5) and Pawluk *et al.* (15) for similar non-degraded and degraded soils.

The pH values and the exchangeable cation data are presented in Table 4.

The exchangeable cation data showed some interesting trends. In the non-degraded soils under grass vegetation (profiles 1, 2 and 3) the magnitude of the cation exchange capacity decreased from A to B horizon following the decrease in organic carbon. In the degraded soils the cation exchange capacity decreased from the A_1 to the A_2 horizon following the decrease in the organic carbon content but it increased from the A_2 to the B horizon following the increase in the clay content. The four non-degraded soils were over 93 per cent base saturated in the A horizons while the three degraded soils were generally less than 83 per cent base saturated in the A_1 and A_2 horizons. In both the non-degraded and the degraded soil sequences the base unsaturation of the soils appeared to increase with increased amounts of water infiltrating into the soil.

The dominant cation in all the profiles was calcium. The per cent of the exchange capacity occupied by calcium generally decreased with depth in the profile until the C_{ca} horizon was approached, and was considerably higher in the non-degraded soils than in the degraded soils. The

TABLE 4.—REACTIONS AND EXCHANGEABLE CATIONS OF SOILS

Soil	Profile no.	Horizon	pH	Calculated C.E.C.[1]	Percentages of exchangeable cations				
					Ca	Mg	K	Na	H
Shallow Black	1	A_1	7.3	33.1	77.9	14.7	4.4	0.1	2.9
		B	7.0	26.3	73.8	19.1	3.3	0.2	3.6
Orthic Black (Newdale Series)	2	A_1	6.8	34.0	73.1	17.0	4.1	0.1	5.7
		B_1	7.2	29.6	66.7	25.8	3.0	0.1	4.4
		B_2	7.1	27.9	62.5	29.6	3.2	0.2	4.5
		B_3	7.7	29.5	69.1	27.2	2.6	0.3	0.8
Gleyed Black	3	A_1	6.7	32.4	71.1	18.9	3.3	0.1	6.6
		B_1	6.2	20.9	67.1	21.6	2.4	0.2	8.7
		B_2	6.2	20.8	65.4	25.0	2.4	0.3	6.9
		B_3	7.3	24.5	77.2	19.9	1.6	0.2	1.1
Calcareous Meadow	4	A_1	7.6	55.6	60.3	34.3	3.6	0.9	0.9
Dark Grey Wooded	5	A_1	5.9	23.0	58.0	19.9	2.8	0.4	18.9
		A_2	6.0	11.6	50.5	27.4	4.0	0.4	17.7
		B_1	5.9	17.1	49.0	36.3	4.0	0.4	10.3
		B_2	5.9	22.5	45.9	39.4	3.1	0.2	11.4
		B_3	7.2	17.4	48.8	44.8	2.4	0.2	3.8
Gleyed Dark Grey Wooded	6	A_1	5.7	22.2	55.2	21.2	3.3	0.4	19.8
		A_2	5.6	17.0	52.9	30.4	3.0	0.3	13.4
		B_1	5.6	22.3	52.0	34.2	3.0	0.4	10.4
		B_2	5.7	26.9	51.4	37.8	2.8	0.3	7.7
		B_3	7.8	29.6	67.4	30.4	1.9	0.3	0.0
Grey Wooded Gley	7	A_2	5.5	7.8	49.9	15.2	9.9	0.8	24.2
		B_1	5.7	26.7	59.2	25.0	4.4	0.1	11.3
		B_2	5.9	30.4	61.3	26.9	3.9	0.2	7.7
		B_3	6.7	25.6	64.1	27.8	3.0	0.2	4.9

[1]Sum of Exchangeable Ca^{++}, Mg^{++}, Na^+, K^+, H^+

per cent of exchangeable calcium in the A horizons also decreased with increased amounts of water entering the soil in both the non-degraded and degraded sequences.

Above the C_{ca} horizon the per cent of exchangeable magnesium increased with depth in these profiles. Unlike calcium the per cent of exchangeable magnesium in the surface horizons appeared to increase as the amount of water entering the soil increased in both sequences except in the Grey Wooded Gley soil where drainage has been retarded. It was also generally true that the per cent exchangeable magnesium was higher in the degraded than in the non-degraded soils.

The per cent exchangeable potassium in general decreased with increasing depth and except for the A_2 horizon of the Grey Wooded Gley profile there were no marked differences in per cent potassium saturation of the two sequences of soils. The relatively high proportion of exchangeable potassium in the A_2 of the Grey Wooded Gley profile was similar to that obtained by Pawluk *et al.* (15) who found the strongly eluviated horizons generally had a higher per cent of exchangeable potassium. The per cent sodium saturation also appeared to be higher in the eluviated horizons and this result also agrees with the findings of Pawluk *et al.*

CONCLUSIONS

The results of this investigation appear to justify the following conclusions:

1. The depth to the $CaCO_3$ accumulation and the per cent of exchangeable hydrogen increased with increasing distance down the slope because of greater amounts of water which have entered the soil in the lower slope positions. Conversely the per cent of exchangeable magnesium appeared to increase with increasing distance down the slope.
2. Tree invasion of the grassland area has resulted in degradation of the soil as shown by the reduced amount of organic carbon in the surface mineral horizon, the marked illuviation of clay and the increased per cent of exchangeable hydrogen. The tree invasion appeared to have been initiated in the locally humid areas found in depressions and on northern and eastern slope exposures.
3. Differences in internal drainage have markedly affected the soil formed in the depression positions. The Calcareous Meadow soil was formed under herbaceous vegetation where internal drainage was impeded. This was indicated by the presence of $CaCO_3$ in the A horizon and the extremely calcareous C_{ca} horizon. The Grey Wooded Gley soil studied in this investigation occurred under sedge-like vegetation but although this was the vegetation for this site at the time of investigation it may not have been the initial vegetation. The Grey Wooded Gley appeared to have had good internal drainage but the heavy B horizon is now relatively impervious.

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NOTE ON A MODIFICATION FOR THE BECKMAN DU FLAME SPECTROPHOTOMETER

Flame photometry is based upon the fact that many metallic elements, upon heating, give off radiant energy of characteristic wavelength. The spectral emission or radiant energy of the element is generally converted into electrical energy by means of a photoelectric cell and is measured with a potentiometer.

The Beckman DU flame photometer (5) utilizes a photomultiplier attachment (3) to increase the electrical response to a given light intensity, thus permitting the analysis of certain elements with greater precision. An AC Power Supply unit for the Beckman DU recently became available and it incorporates the photomultiplier attachment (2). Due to the increased sensitivity, spasmodic phenomena changes in the net radiant energy caused by flame photometric interferences (1, 4) may result in significant fluctuations in electrical energy. The resulting fluctuations of the meter needle create difficulty in obtaining a null and reduces the precision of the analysis of certain elements requiring increased sensitivity. The adjustment of the galvanometer needle to the zero position on a Beckman DU, serial 12641, equipped with a photomultiplier attachment, a condenser assembly, and an atomizer-burner flame attachment, was especially difficult when analysing exchangeable magnesium at the 285.2 mμ wavelength in NH_4OAc extracts of soils. In order to increase the precision of the analysis of magnesium when using an oxygen-acetylene flame with the photometer, it was necessary to reduce needle fluctuation. This objective was attained by simply connecting an inexpensive electrolytic capacitor and a switch across the meter.

A 2000-microfarad, 6-volt DC electrolytic capacitor was connected, in series, to a switch and then mounted, in parallel, directly on the ammeter of the Beckman DU (Figure 1). The humidity-indicating window near the ammeter was removed and the switch was installed in its place. It is important that all electrical leads on the capacitor and switch be well insulated. The capacitor has sufficient capacity to absorb and eliminate most of the fluctuating voltages across the meter, thus stabilizing the meter needle and making precise potentiometric measurements possible. The operator may eliminate the filtering unit by switching the capacitor out of the circuit when recording slowly changing phenomena, as in the determination of potassium.

The capacitor was installed on the Beckman DU prior to the addition of an AC Power Supply unit and of the complex modifications to the photo-

TABLE 1.—TRANSMISSION VALUES (PER CENT) FOR MAGNESIUM AT 285.2 Mμ WAVELENGTH IN NH_4OAc SOLUTION WITH THE CAPACITOR "ON" AND "OFF"

Sample	Capacitor	Mean values (Av. of 5 replicates)	Standard deviation
1	On	20.5	0.24
	Off	22.5	0.51
2	On	60.5	0.27
	Off	61.3	0.74

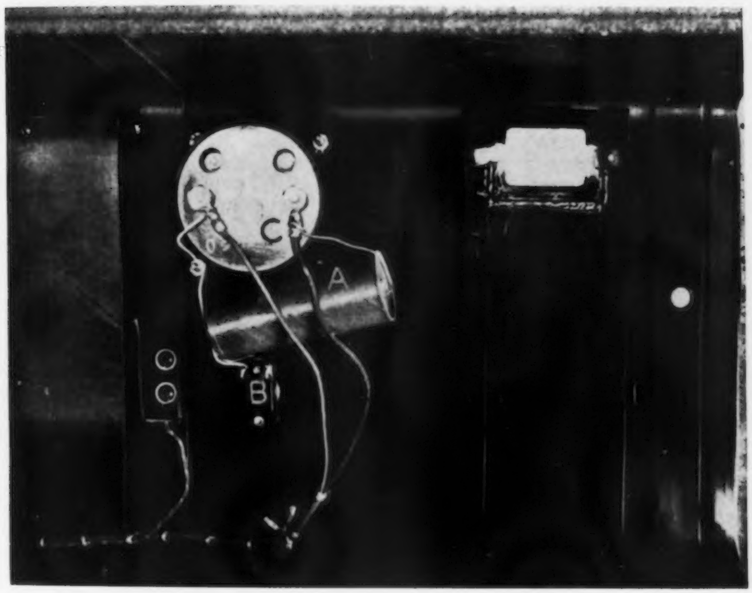

FIGURE 1. The capacitor (A) and switch (B) are shown in position with the ammeter (C) in the inner case of the Beckman DU flame spectrophotometer. The positive terminal of the capacitor is connected to the positive terminal of the ammeter.

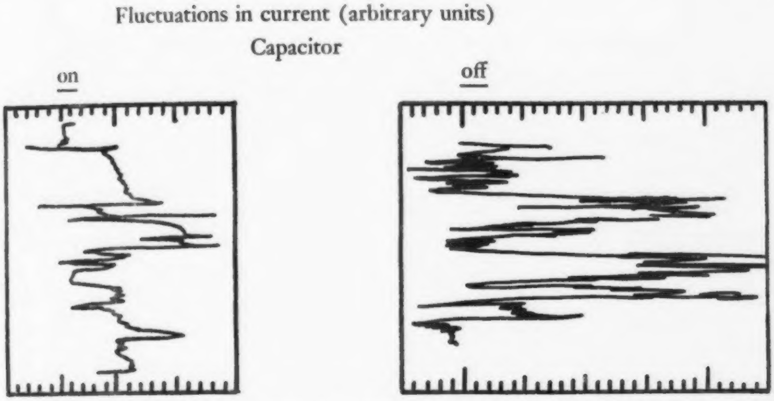

FIGURE 2. Fluctuations in current across the ammeter for a hydrogen lamp at 230 mμ wavelength recorded with a Brown Electronik recorder.

multiplier receiver compartment wiring, in order to reduce the effect of photomultiplier transients. The values in Table I, taken after the acquisition of the AC Power Supply unit, have a lower standard deviation with the capacitor "on" indicating increased precision in obtaining a null reading. The increased stability of the needle with the capacitor "on", when taking reflectance measurements in the ultraviolet range, is shown in Figure 2 by a reduction in current fluctuation. Both before and after the acquisition of the AC Power Supply the use of the capacitor on the Beckman DU has resulted in additional stability of operation.

A capacitor and a switch connected across the meter of a Beckman DU spectrophotometer is an inexpensive and positive method of reducing needle fluctuation which can otherwise occur even when the instrument is equipped with the manufacturers' condensor-assembly. This reduction in needle fluctuation results in increased precision, especially for the analysis of magnesium in NH_4OAc extracts of soils.

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NOTE ON AN AIR-JET STIRRER FOR THE BECKMAN DU FLAME SPECTROPHOTOMETER

The determination of exchangeable and soluble cations in the NH_4OAc and water extracts of soils is accomplished, in this laboratory, by the use of the Beckman DU flame spectrophotometer. Although the concentration of a particular element is closely proportional to the power of the radiation from the flame at a wavelength characteristic of that element (2), this relation frequently does not hold in the presence of other solutes (4). This difficulty is overcome by adding to the standard and the unknown solutions, before analysis, an equal quantity of a "flooding" solution of "radiation buffer" (3). In order to ensure homogeneity, complete mixing of the solutions is essential. This mixing prior to analysis is time-consuming. In this laboratory, 2 cc. of either unknown or standard solution and 2 cc. of a "flooding" solution are both transferred directly into a cuvette by means of a pipette. Mixing of the solutions in the cuvette is achieved by an air-jet stirrer attached on the atomizer-burner mounting block (Figure 2). The air-jet stirs the solutions in the cuvette during analysis resulting in a continuous mixing of solutions.

The air-jet unit consists basically of a tube with a fine bore and a holder. In this laboratory the unit was adapted from an inoperative atomizer-burner. The burner was disassembled according to the instructions provided (1). After removing the fuel jacket, the three screws around the oxygen jacket, and the oxygen jacket, the capillary was pulled out of the sheath by applying heat at the capillary-sheath contact. The oxygen inlet nozzle was cut off near the burner base. The air-jet unit comprises the burner base and the sheath. A 00 (or smaller) rubber stopper was cut horizontally in half and a hole approximately the diameter of the sheath was bored vertically through the smaller portion. This portion was pushed over the inlet of the sheath and a rubber tubing was adapted over the stopper. An opening for the rubber tubing was drilled through the burner housing at a point horizontally opposite the C_2H_2 jacket inlet nozzle along the left vertical side of the mounting block. The air-jet unit was clamped on the burner block at an inclined position relative to the atomizer-burner and cuvette as shown in Figures 1 and 2. The rubber tubing was connected in series through a manometer, filter and dessicant to a pressurized air source. The flow of air through the sheath, directed to the side of the beaker was adjusted (and noted on the manometer) to create a gentle swirling motion of the solution in the cuvette (Figure 2). Transmission readings were taken as soon as the meter needle was steady.

The mean and standard deviation values in Table 1 show that stirring the unknown and flooding solutions in the cuvette with the air-jet stirrer during analysis (Technique 2) is comparable to adequate stirring prior to analysis (Technique 1). Thus, mixing the solutions in the cuvette with the air-jet stirrer is as satisfactory as mixing prior to analysis but it is less time-consuming. The standard deviation value of unstirred solutions in the cuvette (Technique 3) is considerably higher than that of stirred solutions (Technique 2). This indicates that pipetting 2 cc. of sample

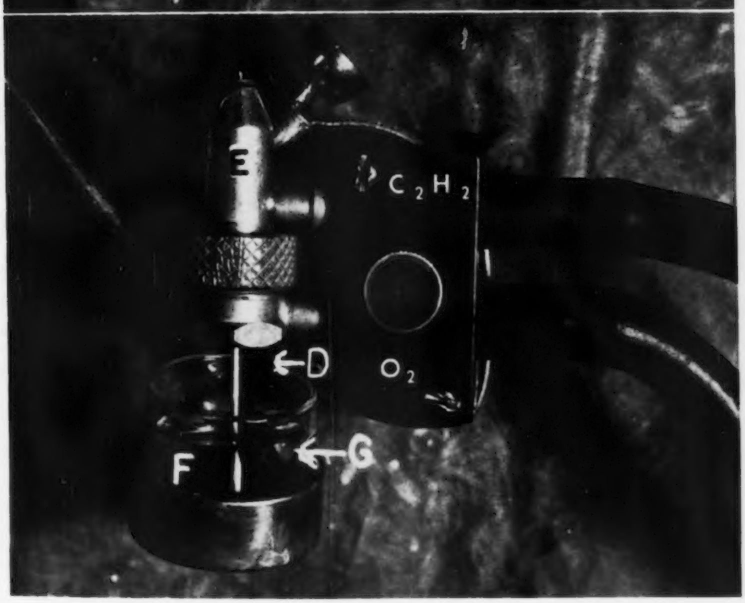

FIGURE 1 (*top*). A view of the air-jet stirrer unit (A) attached to the burner block (B) by a clamp (C) in the flame attachment burner housing of the Beckman DU spectrophotometer.

FIGURE 2. A view of the air-jet capillary (D) with the atomizer-burner (E) and cuvette (F) in position in the flame attachment burner housing of the Beckman DU spectrophotometer. The air-jet directed to the side of the cuvette creates a gentle swirling motion of the solution as indicated by the depression (G).

TABLE 1.—THE ANALYSIS OF SOLUTIONS WHEN STIRRED AND UNSTIRRED DETERMINED AT THE CALCIUM 422.5 MU WAVELENGTH

Techniques	Mean (per cent transmission) (av. of 10 replicates)	Standard deviation
1. Solutions stirred prior to analysis. (5 cc. of unknown and 5 cc. of flooding solution pipetted into a beaker, stirred, then a portion transferred into a cuvette)	78.7	.18
2. Solutions stirred in the cuvette with the air-jet during analysis. (2 cc. of unknown and 2 cc. of flooding solution pipetted directly into a cuvette)	78.8	.19
3. Solutions *not* stirred in the cuvette during analysis. (2 cc. of unknown and 2 cc. of flooding pipetted directly into a cuvette)	77.9	.69

and 2 cc. of flooding solutions directly into a cuvette does not always result in homogeneity of solutions. This is also indicated by the fact that when using the air-jet stirrer it takes 6-8 seconds for the meter needle to remain steady for some samples.

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NOTE ON IMPROVED SOIL BORER FOR SAMPLING IN PERMAFROST[1]

A Courtemanche-type borer described by Potzger (1) has been used at Fort Chimo, Quebec, when installing thermometers down to a depth of 10 feet in permafrost. This borer was modified from the original Courtemanche borer by (a) the addition of carbide tips to the three cutting teeth; (b) slightly increasing the diameter of the core, and (c) changing the method of drive from T handle to hand brace.

Due to difficulties experienced in the removal of the core and in turning the borer by hand brace further modifications were incorporated. The improved borer is described below.

The core barrel (A) of the borer is made from cold-rolled steel tubing 2 inches O.D. and 1⅝ inches I.D. The bottom section, which contains the cutting teeth, is 2⅛ inches long, 2 inches O.D., 1½ inches I.D., and is machined on the inside to give a cutting edge ⅛ inch smaller in diameter than the inside of the barrel, thus providing clearance for the core. This bottom section is threaded and silver-soldered into the main body of the barrel. The carbide tips which provide long wear are silver-soldered into the leading edges of the cutting teeth. The upper end of the barrel is capped by a steel block having a square socket machined into its lower surface. The block is shouldered and silver-soldered into the core barrel. The over-all length of the core barrel is 13 inches, and the cutting edge has an O.D. ⅛-inch larger than the upper end of the core barrel.

The drive and ejector-rod (B), shown withdrawn from the core barrel, is ½ inch cold-rolled steel, to the lower end of which is welded a square block and a 1 13/16-inch flange. The flange serves to push the core from the barrel, while the square block fits into the square socket in the upper end of the core barrel and provides positive drive. The drive and ejector-rod is locked in position in the core barrel by a hex-socket set screw which seats in a groove in the rod. The upper end of the drive and ejector-rod is slotted to receive a key. This assembly is 13¼ inches long, but any length greater than this is suitable.

The lower end of the extension rod (C) and of the drive rod (D) is a slip-fit sleeve inside of which is silver-soldered a key to match the keyway in the ejector-rod (B). This connection is secured by a hex-socket set screw. The upper end of the drive rod (D) is a ½-inch square. These rods can be of any suitable length.

The tool (E) which drives the borer is a 15-inch rachet wrench (Snap-On L-715 or similar) coupled to a ½-inch square socket (Snap-On SW 416 or similar). The socket can be coupled to either the short or long drive rod (D) as required.

The improved soil borer was used in 1960 in the Mackenzie basin to collect samples in frozen gravelly clay loam glacial till and in frozen peat. The carbide-tipped teeth cut through shaly stones quite easily, and cores containing gravel and ice, or peat and ice, were collected and easily removed

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[1]Contribution No. 26, Soil Research Institute, Canada Department of Agriculture, Ottawa, Ont.

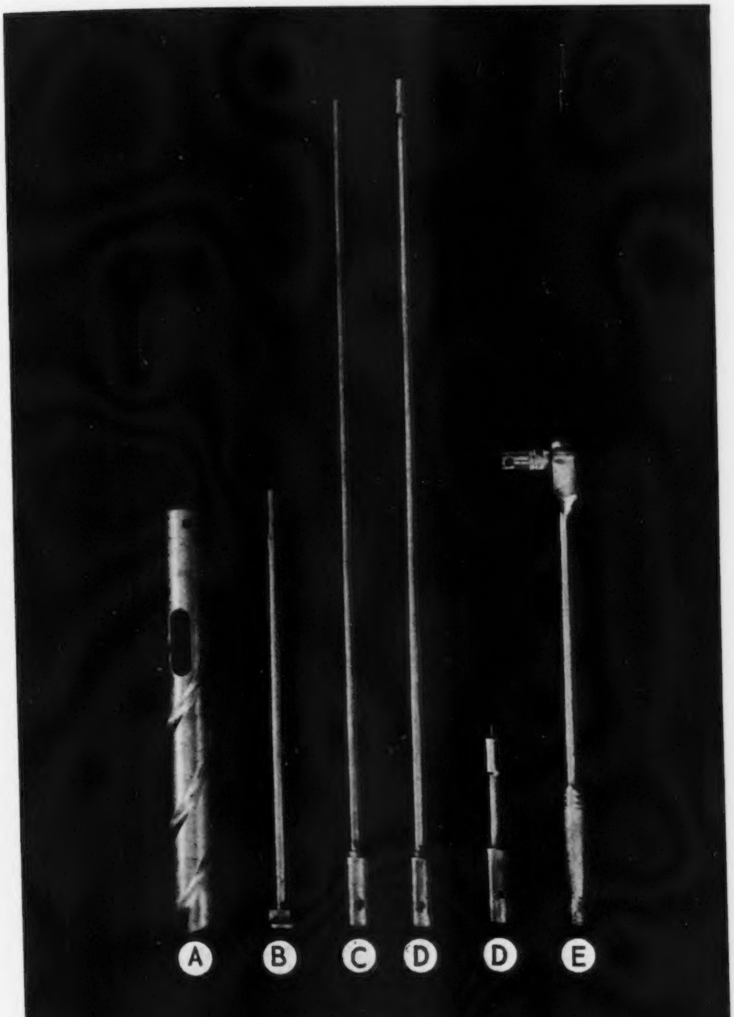

FIGURE 1. (A) core barrel; (B) drive and ejector-rod; (C) extension rod; (D) drive rod; (E) rachet wrench with square socket.

from the barrel. On these gravelly soils the full weight of the operator is required on the end of the borer. The grooves on the outside of the barrel were ineffective in bringing up the shavings, at least in clayey soils, since they became filled with sticky clay. When drilling at depths greater than 12 inches the clean-out ports picked up some mud from the sides of the hole, but this in no way lessened the effectiveness of the borer. The borer is capable of working to a depth of about 6 feet or more depending on the length of the extension rods used.

A full-scale plan showing details of construction and assembly is available on request from the Engineering Research Service, Canada Department of Agriculture, Central Experimental Farm, Ottawa.

ACKNOWLEDGEMENT

The authors wish to acknowledge the helpful suggestions and assistance of Carson MacDonald, who built the borer.

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